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On the Influence of Complexity and Dissimilarity on Memory

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PREFACE.

While the investigation contained in the following pages belongs to the field of pure psychology, the motives which prompted it were considerations rather of educational psychology, and it is believed that not the least of its significance will be found in its bearing upon certain problems in this latter field. The experiments were carried out at the University of Chicago during the year 1908–9. The subjects were eleven graduate students in the Department of Psychology, of whom seven were men and four women. Messrs. E. B. McProud, W. C. Vogt, H. Kimmel, F. A. C. Perrin, J. W. Hayes, E. H. Sutherland, and J. W. Baumgardner, and Misses Emma Felsenthal, Mary C. McIntosh, Edith Turner, and Jeanette Obenchain. Two of them, Mr. McProud and Miss Felsenthal, were obliged by pressure of other work to withdraw after the Gray and the Violet Sets and the Renaissance Set had been completed. Their places were taken by Mr. Baumgardner and Miss Obenchain. In the latter part of the year supplemental experiments, described in V–3, were carried out with Messrs. Sutherland and Hayes and Miss Turner. They did not participate in the earlier experiments.

For the splendid spirit in which all eleven carried out their part of the investigation I wish to express to them my deep appreciation and heartfelt thanks. To Professor James R. Angell, Director of the Laboratory, and to Professor Harvey Carr and Dr. Karl T. Waugh I am glad of this opportunity to express my sincere thanks for assistance in the formulation and execution of the work.

HARVEY ANDREW PETERSON.

CONTENTS

ON THE INFLUENCE OF COMPLEXITY AND DISSIMILARITY ON MEMORY

HARVEY ANDREW PETERSON

I. HISTORICAL INTRODUCTION AND PROBLEM

The question of the relative persistence in memory of different kinds of materials has been worked out to a considerable extent. It is known that words in the form of connected passages are vastly better retained than an equal number of disconnected words or phrases; and that objects, actions and pictures are better retained than their verbal equivalents. Numbers and abstract words belong to the third stage of difficulty, while nonsense syllables are the most elusive and most quickly forgotten of all materials commonly used for experimentation. Presentation of the materials to several senses is more effective than presentation to one only. Up to a certain stage—where the limit is we do not know—complex material is retained better than that which is simpler; and recurrent similarity in the presentations of series otherwise different is disastrous. Why all this should be true is not so easy to find out. There has been little attempt to seek explanatory principles which would unify these diverse facts. The relations of complexity and similarity are both intricate and close. It is believed that a comprehension of their relations will afford a unifying principle for some of the other facts we have enumerated. These relations are apparently somewhat as follows, so far as they have been worked out. We may first take complexity.

A thing is complex when it has many parts and the parts have many interrelations, that is, the whole has a high degree of organization. A telephone exchange is complex when in operation, while a corresponding quantity of wire, colored glass and electricity is simple because unorganized. But the

fewer the parts the simpler the whole because the possibilities of interrelation are less.

Complexity affects the memory through interest and attention. The simple is easily mastered. The parts and their relations are few and the content is soon exhausted. The complex, provided it is not too far beyond us, whets our curiosity. It gets the attention and the thing is in so far better remembered, because it stays in consciousness long enough to make a deep impression. But the complex has a superiority in recall as well as in presentation, because of the high degree of organization. This makes it a unity. One part brings others. A general idea of the whole is also a very effective starting point for recall. We pass to the experimental literature.

Meakin demonstrated the superior persistence of the complex over the simple in passive attention.[1] He exposed a line and an angle together for five seconds directing the subject looking at them to divide the time equally between them. As soon as the exposure was over the subject closed his eyes and remained passive for sixty seconds reporting the entrance and exit of the two images. The angles were in consciousness an average of 38 seconds; the lines, 32 seconds. In the same way he compared plain figures and identical figures with concentric lines just inside the periphery, plain and identical colored figures, and figures of less and of more complex outlines. His results were, for the plain and the marked, 24 and 37 seconds; for the plain and the colored, 31 and 38 seconds; for the simple and the complex outlines, 27 and 35 seconds.

Binet and Henri compared the memory of school children for disconnected words and for sentences, the material being read to the children.[2] Although the comparison was not carried further than lists of seven or eight words, it was found that about twenty-five times as many words were recalled from the sentences as from the lists containing equal numbers of words. The reproduction was immediate. Mere connecting words in the sentences were disregarded.

[1] *Psych. Rev.*, 1903, Mon. Sup., no. 4, p. 235.

[2] Binet and Henri: *L'Année Psych.*, 1894, I, 1–59.

Dr. Gordon introduced a novelty into memory work when she made the complex material consist of combinations wholly *unfamiliar* to the subject.[1] This property cannot be claimed *in toto* for sentences, since the past experiences of the listener render them a unity to some extent, even before they are heard. Dr. Gordon's simple material consisted of series of nonsense syllables, nine in a series, shown through a single aperture. With this she contrasted three types of complex series in the first of which each syllable had a background of a different color. In a second type the syllables were black like the simple type, but were shown through nine apertures distributed around the periphery of the screen; thus each syllable had a distinctive spatial position. In a third type the backgrounds were colored and the positions were also changed, the apertures forming a vertical column in the middle of the screen. The standard of measurement was the number of repetitions required for complete learning, and relearning after a day, and in the test the question was not how many of the combinations of color, position and syllable can the subject recall, but merely how many syllables can be recalled. The novelty of the experiment consisted in the expectation that the secondary associations of syllable with color and position would be formed *during the brief period of learning*. Unquestionably these complex series were at a disadvantage compared with the simple series because of the burden thus imposed, but on the other hand in recall they possessed the theoretical advantage of furnishing the subject with more recall cues, namely, the color and the spatial location of the syllables. Kuhlmann has shown, what was suspected before, that spatial location is one of the most easily formed and most lasting associations.[2] The principle involved has been stated by James, that other things being equal, the chances of a fact being recalled are in proportion to the number of connections between it and the rest of our experience.[3] The results of the Gordon experiment showed a decided advantage for the complex series. The fig-

[1] Gordon, K.: Meaning in Memory and Attention. *Psych. Rev.*, 1903, X, 267.

[2] Kuhlmann, F.: *Psych. Rev.*, 1906, XIII, 321.

[3] James: *Principles of Psychology*, I, 661.

ures give the average number of repetitions required for learning and relearning.

	First learning	*Second learning*
Plain syllables shown in one place	7.05	4.06
Plain syllables shown in nine places	6.60	3.63
Plain syllables shown in one place	6.04	3.40
Colored syllables shown in one place	5.62	2.79
Colored syllables shown in nine places	5.27	3.26

Dr. Gordon suggested that the advantage of increasing the complexity in this way would soon reach a limit, where more potential clues would be offered than the learner could use in so short a time of learning, and where distraction would begin to operate. It is the main problem of the present investigation to find these limits in a few typical cases.

If the mind loves complexity somewhat, it loves variety and change at least as much,—common sense would unhesitatingly say, more,—and here again it is through the superior hold which variety has on our attention and interest that the memory is improved. Let us first distinguish the pair, variety and sameness (or similarity), from complexity and simplicity; for though they have much in common they are not identical. Two things are varied when one is more or less different from the other, has something not contained in the other. It is true that variety presupposes complexity, for without a plurality of parts and relations some of which are now included and now left out, variety is impossible. But the converse is not true, for the same complex may recur without affording much variety. The simple usually has sameness about it, though it may have that low order of variety which comes from a mere change of parts, as when one changes from a collection of colors to one of letters. There is little complexity in either because of the relative absence of organization. *The distinction which will be significant for the present investigation is the fact that one might increase the complexity without necessarily increasing the variety.* It is the *varied* complexity which in our opinion seems fruitful for memory and which the present investigation is concerned with.

The beneficial effect of considerable variety upon memory is a commonplace. A speaker who uses only a few tones is at a disadvantage compared with one who uses intonation properly. School programs rotate their studies with an eye to variety, and not only interest but memory directly profits by the change. Much of the bad effect of prolonged sameness in work is traceable to fatigue, but not all, as we shall see. All memory is associative. There is no such thing as memorizing things without relating them. With prolonged sameness or similarity the associations derived from a presented material, quite apart from fatigue, become confused with one another, jumbling begins, and the memory weakens, unable to straighten out the tangle of similarities. On the contrary the dissimilar are much more easily kept apart, and fatigue is less.

In the experimental investigations variety is quite commonly spoken of as vividness. Miss Calkins' investigation is well known.[1] Numbers were associated with colors in couplets, twelve couplets constituting a series. To speak first only of the vividness experiments proper, all the numbers in a series except one were black two-place numbers, the one remaining was a three-place number or had red figures, or was differentiated qualitatively from the others by some other similar means. One of the ordinary numbers was associated with the same color as the vivid number. Thus the series of twelve couplets consisted of ten ordinary couplets, one critical couplet, and one so-called normal couplet which competed with the critical in recall. The ordinary and normal couplets were two different standards of comparison for the critical pairs. In the test for immediate recall the subject was shown the colors in altered order and was asked to give the numbers which had been shown with each. The repeated color was shown only once. It might recall the vivid number alone, or both the vivid and the normal number, or the normal alone. The vivid number was recalled 52 per cent of the possible number of cases, the normal 21 per cent, while the general average of recall for the ordinary combinations of all the series was 26 per cent. Thus

[1] Calkins, M. W.: Association, *Psych. Rev.*, 1896, Mon. Sup., no. 1.

we have a measure of the effectiveness of *this kind* of vividness.[1] In other experiments the critical number was the same as the rest of the series in all respects save that it was repeated three times. This measured the effectiveness of repetition. In a similar way other experiments tested the worth of the first and last positions in the series (primacy and recency). All four kinds of critical couplets were superior in recall to the ordinary and the normal combinations by varying amounts.

The analysis of the relations of sameness and variety made in the preceding pages leads us to an interpretation of this experiment which is quite different from that of Miss Calkins. Just because there was only one of the critical pairs while there were eight or ten of the ordinary pairs in a series, all four types of experiments (vividness, frequency, recency and primacy) are studies in the effect of variety. All four of the critical couplets are a change from the sameness of the other couplets of the series. The superiority of the frequent couplet for example is due in some measure to the fact of its repetition. But its superiority is due quite as much and perhaps more to the fact, already mentioned, that the other couplets of the series are all pretty much alike, while the frequent couplet affords a change, amid sameness. It is extremely probable that if the relations were reversed, the mass of the series being given the threefold repetition and the critical couplet being given only once, the critical couplet would still be better remembered, providing that the subject knew which was the critical couplet when he saw it.[2] In the experiments of Miss Calkins on frequency the second repetition of the critical couplet furnished this clue. The isolation of the frequency factor from the sameness-variety factor could be secured only by repeating *one-half* of the series a larger number of times than the *other half*.[3]

[1] The italics are ours.

[2] "It is not the mere intensity of the stimulus which is effective in attracting the attention so much as it is the change in intensity. . . . A negative change will have the same general effect." Pillsbury: *Attention*, pp. 28–29. The same is true of memory to a less extent.

[3] The question has been worked out with nonsense syllables in the form of the worth of the individual repetitions. Cf. Ebbinghaus: *Grundzüge. d. Psychol.*, I, p. 652. Zweite Auflage.

Take next the results on primacy. Suppose that the length of the series had been three couplets instead of twelve, and that the color which had stood in the first place had been repeated in the middle place with a different number: Would primacy have been worth any more than normal (here the middle)? Probably not. Then primacy is purely another form of vividness. There is no other factor involved, as there was in the frequency case. The experiments on recency involve two factors, recency and sameness-variety. The worth of the former is attested by the fact that in memory work in general the terms just preceding the last are better recalled than their immediate predecessors. But the last term is so *very much* better recalled than the term just preceding it (which is almost as recent), that the sameness-variety factor is much the larger one.[1] To summarize the foregoing criticism, frequency and recency improve the memory apart from the question of sameness and variety. Vividness and primacy are simply species of variety. But the fewness of all the critical combinations compared with the large number of ordinary combinations gives the critical ones the advantage which comes from a change from the routine, and in view of the greatness of the numerical disparity, the whole investigation is a study mainly of different forms of vividness or, in our own terms, of variety.[2]

Aside from Miss Calkins' investigation, and the one by Dr. Gordon already described (which may be viewed as an experi-

[1] Cf. Ebbinghaus: Op. cit., p. 653. Müller and Pilzecker: *Ztsch. f. Psych.*, 1900, *Ergänzungsbd. I, p.* 264.

[2] It is significant that the percentages of recall for the normal numbers were usually less than that of the ordinary combinations. The fact is another illustration of the disastrous effects of similarity. The critical color and the normal number together are similar to the same color and the unusual number taken together. If ab bc stands for these two couplets respectively, given b (the common color), a has by no means as Titchener says (*Experimental Psychology*, vol. I, pt. II, p. 407) "a chance equal to that of the other terms of the series," for it is interfered with by a competing association, bc. For the same reason the figures given for vividness, frequency, etc., *in so far* underestimate the value of the factors since interference is always mutual. Of course the factor of dissimilarity contained in them much overbalances the interference.

ment either in variety or in complexity[1]) the writer is not aware of other experiments on the positive effects of variety. There are however a number of important and extended researches on the negative side, namely, the injurious effects of increasing similarity of associations, in comparison with which the material free from the similarity is relatively varied.

Müller and Schumann found that syllables which had been used once in old series were more difficult to learn in new series than syllables which had not been used before.[2] The old associates either appeared in consciousness and hindered the formation of the new connections, or there was a purely physiological interference manifested by the poorer recall. Here the old series and the series in which they were used again constitute together the less varied material, while the series not re-used are the more varied material.

Müller and Pilzecker made an exhaustive study of interference using nonsense syllables.[3] These experimenters demonstrated that in the case of two associations of the type ab bc the interference is mutual. Their method was in principle the same as that of Müller and Schumann, except that they employed the method of successes. Each day the subject learned four antecedent series and an equal number of sequent series. The antecedent series were normally constructed eight-syllable series. They were read in trochaic rhythm, hence each series fell into four feet, a foot containing an accented and an unaccented syllable. The series were given a fixed number of repetitions and in the recall (to come later) the subject was given the accented syllables in altered order and asked to give the unaccented ones which had accompanied each. After

[1] Because the increase was in the direction of *dissimilar* complexity. The spatial positions and the colors which were added to the syllables were themselves varied.

[2] Müller and Schumann: Exp. Beiträge zur Untersuchung des Gedächtnisses. *Ztsch. f. Psych.*, 1894, 6:177 and 318. Also Müller and Pilzecker, who on p. 83 in the work referred to in the following note summarize Müller and Schumann's results.

[3] Müller and Pilzecker: Exp. Beiträge zur Lehre vom Gedächtniss. *Ztsch. f. Psych.*, 1900, Ergänzungsbd. I.

learning the four antecedent series the subject was given the four sequent series. These were formed by combining two of the accented syllables of the antecedent series with new unaccented syllables. This furnished two of the four feet, and the other two were made of new syllables. The series may be symbolized thus:

Antecedent series: *a*b cd *e*f gh.
Sequent series: ij *a*k lm *e*n.

After learning the four antecedent and first sequent series the subject was tested on the first antecedent and the first sequent series. Then followed the learning of the second sequent series and the second pair of tests, and so on till all eight series had been learned and tested. The half of the couplets represented by the letters cd, gh, ij, and lm may be called the normal couplets; the other half, ab, ef, ak, and en, the interference couplets. The former were simply a standard with which the interference in the latter might be compared. When the antecedent series was tested (by giving a, c, e, and g), k and n interfered with the recall of b and f. When the sequent series was tested (by giving i, a, l and e), b and f interfered with the recall of k and n. The following are typical results.

Percentage of Correct Recalls.
(Number of couplets 168)

	Per cent
Normal Couplets, Antecedent Series	66
Interference Couplets of same	36.5
Normal Couplets, Sequent Series	63.5
Interference Couplets of same	52.5

The next day the tests were repeated and the relations of the two interference groups to their respective standards were found to be reversed. It was now the sequent series which showed by far the greater loss. This reversal is a study in the effects of recency, into which it is beside our purpose to go.[1]

[1] While the second learnings were still fresh in mind a and e suggested their second associates without *much* difficulty. But when the tests were put off or repeated later, the first associates became the stronger.

The extent to which the interference might go may be seen in the fact that in some cases the interference recall in *both* antecedent *and* sequent series together was less than the normal recall of the antecedent series.

It is probably unnecessary to point out the relevancy of these experiments to the question of the effects of similarity and variety upon memory. The normal couplets are relatively a more varied material than the interference couplets. While the sameness in the latter is planned with malice aforethought, so to speak, the same thing happens in daily experience where the sameness is unintentional, and not so exactly measured. The experiments of Ranschburg with numbers, described below, illustrate how daily experience is full of the ab bc type of similarity.

Ranschburg has confirmed the results of Müller and Pilzecker and Müller and Schumann.[1] Most of the details are omitted here because of their similarity to the two works last described. Using the method of successes this author arranged what he calls heterogeneous and homogeneous series. The heterogeneous were simply normal eight-syllable series. Of the homogeneous the *first* series was also normal, but the rest were not, for they were all identical with the first in respect to their consonants. Only the vowels were changed in each succeeding series. These two kinds of series were learned in parallel fashion. The confusing result may be imagined, especially when an accumulation of eight series of each kind, the learning of which had extended over a number of days, was given a few renewing repetitions and then tested "run together." His experiments with words are somewhat newer. In these latter various series of word-couplets were devised in which the words in a couplet were closely germane in thought, but the couplets were drawn from quite disparate thought universes. In other series the couplets were internally as before, but several couplets were drawn from similar and in some cases practically the same thought universes. The similarity

[1] Ranschburg. P.: Ueber die Bedeutung der Aehnlichkeit beim Erlernen, Behalten, und bei der Reproduction. *Z. f. Psych. u. Neur.*, 1905, 5:93.

was entirely on the side of thought. In recall the subject was very much more certain of the dissimilar series, and the percentages of recall were much higher than in the similar series. In the latter the subject was quite apt to hesitate between the correct response and a word in another couplet which was similar in meaning, but might be quite removed in the time of learning.

In another investigation on the conditions of perception of similar and dissimilar numbers Ranschburg showed that the fusion of similar things which we have seen taking place in *memory* exists even in the *perception*, when the time of exposure is short.[1] Indeed he traces the memory confusion back to perceptual confusion, in cases where the successive presentations possess considerable similarity. The experiment is for this reason relevant to our problem: it offers an explanation for a considerable part of the interference in similar memory material. It is also important for our problem because it endeavors to measure the degree of interference due to *inherent* similarity, and not to the fact that the associations were made to interfere. In experimenting upon the span and accuracy of visual perception, using six-place numbers exposed one-third of a second, Ranschburg observed that a large proportion of the errors were traceable to the inherent similarity of certain figures, for example 6, 9, and 0, 3 and 8, 9 and 2, 1, 4, and 7. He was able to determine the nature of the errors with considerable certainty because in nearly all cases they involved only one or two figures, and the figures were nearly always in the fourth or fifth positions, less often in the third, from the left. Where only one figure was wrong, it belonged in nearly every case to one of the five following types: (1) Substitution of a similar reproduced number, e. g., an 8 for a 3; (2) assimilation to a similar nearby figure, e. g., 684223 instead of 684293; (3) assimilation to a dissimilar nearby figure, e. g., 162445 instead of 162845; (4) change of one of two identical figures to any other figure; (5) substitution of a figure either preferred for

[1] Ranschburg: Ueber Hemmung Gleichzeitiger Reizwirkungen. *Ztsch. f. Psych.*, 1902, 30:39.

some temperamental reason or connected closely in experience with the given figure. The fifth seldom occurred. Where two figures were wrong nearly all the cases were either simple inversion (78 instead of 87) or a combination of inversion with one of the types enumerated above. The first four classes of errors are types of similarity. The fifth and inversion are not. The large proportion of similarity errors makes it highly improbable that they are due to chance.

In the light of this statistical analysis of the errors in numbers not devised to test similarity, but cut from a statistical handbook, he constructed numbers of several different kinds of similarity for the purpose of finding out whether "the threshhold of perception is higher for homogeneous than for heterogeneous material." In the first experiment he gave in the same way as before 20 six-place numbers lacking similarity internally, and 20 six-place numbers two figures of which, usually in the right part of the series, were identical, e. g., 119495, or 141993. In a second experiment the critical figures were only similar. The results confirmed his hypothesis. Where two of the figures were similar, the errors were about three times as great as in the dissimilar numbers, but where two figures were identical, the errors were four times as great as in the dissimilar numbers. The threshold of perception is therefore higher in proportion to the similarity. These figures are valuable because they are among the few, to the writer's knowledge, in which the amount of visual similarity is controlled. Whether they bear upon the effects of similarity on *memory* is another question. There is no objection to viewing the responses of the subjects as immediate recall, providing the conditions of exposure are comparable to the conditions of exposure in memory work. It may be said that in memory tests the subject is assured of a long enough interval to properly perceive the material. But it may be quite fairly said in reply that while the absolute exposure is usually much longer than was used here, *the adequacy of it to distinguish the terms from each other depends upon their similarity.* I should say that the conditions are comparable to those in memory in many cases. On the other hand the confusion in such experi-

ments as those of Müller and Pilzecker are not confusions in perception but in memory.[1]

To summarize the various investigations of the influence of relative sameness and variety on memory: anything which serves to distinguish a thing from a group makes it better remembered. A greater length, a different color, a more frequent repetition, an unusual position spatially or temporally are some of the variations which have been shown to be effective. Where the similarity results from the triangular association of two things with a third, if the recall proceeds from the common element towards one of the extremes, the other extreme interferes and diminishes the chances of recall. The result is the same if the start be made toward the other extreme. The conflict may be purely physiological, and apparent in consciousness only as a delayed recall. The injurious effects of similarity are however not confined to artificially constructed overlapping associations, but also occur where the similarity is inherent in the nature of the material. In contrast with this, wherever the different parts of the material learned are dissimilar, the associations are more lasting and their recall proceeds more promptly, because they do not interfere with one another. It has also been shown that the threshold of perception is higher for similar material than for dissimilar. It requires a longer time to get a clear perception of a material the parts of which are similar than it does of one the parts of which are not similar. The differentiation here referred to is however purely involuntary and almost instantaneous. If the perceiving process is cut off before clearness has been reached,

[1] Other experiments on the effects of similarity on memory are those of Bergström on the interference arising from sorting the same cards into different arrangements of the same positions, in *Am. Jour. of Psych.*, 1893, V, 356, and 1894, VI, 432. Also Münsterberg, in *Beiträge zur Exp. Psych.*, Heft 4, p. 69. Both of these deal with the interference of automatic habits of movement. The latter shows how opposed habits, after being made automatic separately, may be used for alternate periods of considerable length without interference, e. g., keeping one's watch first in one pocket and then in another, the same arm being used for both movements. It certainly offers something for reconciliation with the otherwise uniform outcome of the similarity literature.

the errors in recall are largely of the type of confusion of similars.

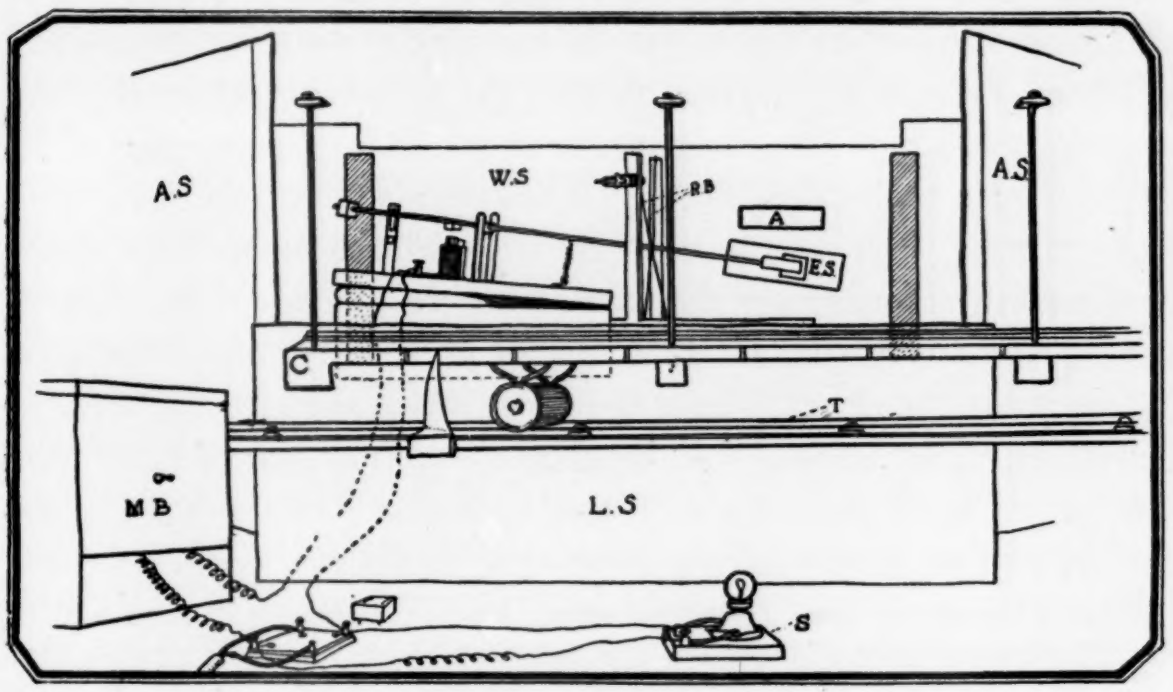
Summarizing the influence of complexity on memory we may say: the complexity afforded the mind by sentences or connected passages is superior to the simplicity of disconnected words because of the unity of the whole passage and the resulting greater differentiation of the parts. In assimilating a simple linguistic material such as nonsense syllables, letters or even disconnected words, a person not only tries to give it a unity by connecting it with his experience, but also seeks differentials by which to distinguish the parts; and in the absence of preformed associations which may serve the purpose (for example the English words suggested by nonsense syllables), any peculiarity such as spatial location, background, etc., will be utilized. But the peculiarities thus utilized are increases in complexity. In these cases the secondary associations (location, background, etc.) are formed during the memorizing of the principal associations.

We are thus brought to the problem of the present investigation. Two factors are involved which are inversely related to each other. Increasing the complexity diminishes the similarity, and this is favorable to memorizing. On the other hand, *if the material is not a unity in advance*, complexity increases the association processes, the mental effort presumably required, and consequently the possibilities of distraction. *Under these conditions* how much will variation added to a material, highly similar in itself, shorten the learning time and improve the retention? Is there a resulting profit to the memory only when the original material is highly similar, or may it possess considerable variety? When does distraction enter? Is there a relation between the amount of complexity which a person will make use of and his retentiveness?

II. APPARATUS

With slight changes the same apparatus was used throughout the investigation. The essential part was an electro-magnetic shutter which by its movements opened and closed a small

aperture in a screen. The screen was 2 m. 11 cm. long and 58 cm. high. Near the middle was an aperture 9.5 cm. wide and 2 cm. high. The subject sat in front of the screen, and when he looked at a series he brought his eyes within about 3 cm. of the aperture. Behind the screen, 74 cm. from it and parallel to it, was a track somewhat longer than the screen, supported by adjustable standards, and carrying a car 1 m. long and 11 cm. wide. On the floor of the car and running the length of it was a groove, into which any kind of series



EXPOSURE APPARATUS

The apparatus is described in the text. *A* is aperture; *E S*, electro-magnetic shutter; *T*, track; *W S*, wide screen; *C*, car; *A S*, adjustable screens; *L S*, lower screen; *S*, shunt; *M B*, metronome box; *R B*, rubber bands, upper and lower, which limit the play of the shutter.

mounted on heavy cardboard could be slid preparatory to exposing it. On the back of the car were four upright steel rods 25 cm. high on the top of which were four spring clasps. Small cardboard flaps on the back of the series when put into the spring clasps held the series rigidly in place. Two black screens 71 cm. high and 56 cm. wide, extending from the large screen on the front of the tables to the track, could be so adjusted by the operator as to confine the subject's gaze to as

small a space as desired. They could be widened so as to expose a whole series at once. The car would of course then remain motionless during exposure. Or they could be narrowed to the width of a single term of a series, 15 cm. for example. For successive exposure the car would then be moved past this space by the operator during the intervals while the aperture was closed. The great advantage of the apparatus was that whenever the subject was looking the series did not move. A scale, 25 cm. in length on the front of the track, enabled the screens to be quickly adjusted to any desirable width. The operator was cut off from the subject by a strip of cardboard extending across the upper part of the space between the converging screens. The essential part of the apparatus, the shutter, remains to be described. This consisted of an iron lever 53 cm. long carrying a movable counterpoise on the short arm and the shutter on the end of the long arm. An electromagnet under the lever drew down the short arm when the circuit was closed, at which the long arm carrying the shutter moved up and closed the aperture. When the circuit was broken a coiled spring connected with the wooden base drew the arm down and thus opened the aperture. The current was led first to the commutator, then through the electromagnet and a metronome. A small rheostat connected at the commutator with the apparatus furnished a shunt to the current at the moment when it was broken by the metronome. The metronome, enclosed in a felt-lined box, regulated the movements of the shutter, while a small rod passing through the wall of the box intercepted the pendulum or set it free when desired. A year's constant use of the apparatus has led to the conclusion that it is a satisfactory exposure mechanism for memory work of this kind.

III. EXPERIMENTS WITH LANGUAGE MATERIALS

The first effort was to extend the experiments of Dr. Gordon. Series of nonsense syllables of the length used by her (nine syllables) were varied in *size, color and style of type*. The rules of Müller and Schumann were followed in constructing the

series. No syllable was used twice. The variations were first tried out separately and later in combination. Variations in size were secured by using Willson Gummed Letters numbers 1, 20, 21, 23 and 25. The largest letters were 38, the smallest 7 mm. high. The letters were all of heavy type, the lines of the largest being 8 mm. thick. Thus a strong difference in sensation was secured. A medium size, No. 21, was used for the standard and colored series.[1] Color variation was obtained by painting white letters red, orange, yellow, green, blue, brown, neutral gray, and black. White furnished the ninth variation. In the series in which the size varied there were two syllables in each of four sizes and one in a fifth size, while in the color-varying series each syllable was of a different color or brightness. Five different styles of lettering were used in the form-varying series, all presenting, as nearly as could be, about the same area of stimulating surface as the standard letters. The styles of type used were the most varied that could be found and still be legible. They were (1) a heavily shaded style of print, (2) old English, (3) plain script, (4) an alphabet of closed letters similar to the old English, but having more flourishes, and (5) an alphabet of hollow letters. All of these were done in black by hand. Four series of each kind of variation, size, color, and style of type, were given to six subjects without varying the spatial position of the syllables.[2] Thus the value of each variation separately was obtained. The effects of practice were distributed by giving four series each week, one of each kind, and rotating the time situation of each kind each week. A hard rubber mouth piece held between the teeth was used to aid the subject in eliminating enunciation. It was found as shown in the table below that in immediate recall the series varying in size gave slightly better results than the standard—a gain of 9 per cent, but that color variation was of no aid, while variation in the style of print was a detriment. In recall after 24 hours, however, the result was quite different. *Size was again the*

[1] The standard series did not vary in size, color or style of type. They were the standard with which the others were compared.

[2] For further details, see p. 25.

best variation, showing a gain over standard of 58 per cent. Color was next with 32 per cent gain, while even form variation showed a gain of 19 per cent.[1]

The next step was to increase the complexity by combining the variations. In each syllable shown him the subject faced a new combination. The most complex type were series which varied in four ways: size, color, form or style of lettering and spatial position. A second type varied in two ways only, the two which in all probabliity were the most effective singly, namely, position and size. The third type was simply the standard without variation in position. Four series of each were given as before, and it was found that one had not far to go to reach the limit of effectiveness in this direction. In immediate recall the two variations showed a gain of 15 per cent, while the series containing four was no better than standard, a gain of 3 per cent. *In recall after 24 hours the two variations showed a gain over standard of only 4 per cent, while the four gave the same as standard again. The improvement shown by the subjects in the standard, 56 per cent gain over the showing made in the first four weeks, is worth noting.* It is due to practice. The unexpected fact is that the size variation with the addition of position variation has not gained proportionately. This is probably due to a concealed loss consequent upon increasing the complexity. In any case taken with the fact that four variations gave the same as none (5.21 and 5.21), it shows that the limit has been reached with this material, unless more effective variations can be found.

During the fifth and sixth of the eight weeks spent on syllables, the combination of size and position, and the combination of four variations were tried with words. It was expected that the variations would be of no positive value here because words contain so much variation in themselves, especially in meaning, as compared with syllables. The result as shown by the table, based on two series of each kind, confirmed the expectation. Interesting light is thrown by the introspections of the subjects on the cause of the failure. They made mean-

[1] The six horizontal rows of figures in the tables represent the six subjects, and give the average number of syllables or words out of nine correctly recalled.

ing-classifications such as 'farm products' or 'machinery,' which united not only two or more words in the same series, but even words from different series. With rare exceptions, position was the only mechanical aid, but even it was not needed in view of the variety afforded by meaning. In syllables they found variety in ways not provided by the operator, all of which is on the positive side of our thesis, but which cannot be reduced to tables. At the outset of the experiment the subjects were asked to lend their coöperation in shifting the emphasis of the attention to the variations introduced by the operator, and they did so. Nevertheless, resemblance to words, despite their efforts to exclude it, was one of the two main aids in recalling the syllables, the other being position. The fact that an error had been made in the case of a certain

TABLE I. *Showing averages and mean variations.*

A. NONSENSE SYLLABLES.

Immediate Recall.

EFFECT OF VARIATIONS TAKEN SINGLY.								EFFECT OF COMBINING VARIATIONS.					
Standard.		Colors.		Sizes.		Forms.		Standard.		Two Var.		Four Var.	
Av.	M. V.	Av.	M. V.	Av.	M. V.	Av.	M. V.	Av.	M. V.	Av.	M. V.	Av.	M. V.
6.25	1.25	6.84	1.01	7.92	.29	6.67	.50	7.34	1.00	8.41	.29	7.00	.50
6.67	1.17	6.75	.46	7.42	1.04	4.92	.79	6.59	.79	8.00	1.00	7.58	.80
7.33	.83	7.34	.34	8.50	.75	6.08	1.54	6.17	.83	6.83	.96	6.33	.83
5.25	1.75	4.50	1.00	6.00	.84	5.42	.92	8.33	.66	6.66	1.33	7.16	1.42
5.25	.29	5.92	.77	6.17	.59	6.09	.90	6.42	1.08	9.67	2.00	7.17	1.17
7.08	1.59	6.75	.88	5.33	.50	5.75	1.75	5.33	1.08	6.50	1.00	6.00	1.00
6.31	1.15	6.35	.74	6.89	.68	5.82	1.08	6.70	.91	7.68	1.10	6.88	.96

Recall after Twenty-four Hours.

3.25	1.38	4.25	1.88	4.00	1.00	3.75	1.75	7.25	.88	7.25	1.25	7.25	1.75
4.25	1.19	3.25	1.38	5.50	1.25	4.50	1.50	4.75	1.88	5.75	1.38	3.50	1.25
.50	.75	3.75	1.25	3.75	.75	2.25	1.19	5.50	1.50	6.25	1.75	4.75	1.25
2.25	.38	4.00	.50	4.50	1.50	3.25	1.25	2.50	1.55	2.25	1.38	3.00	2.00
4.25	1.25	5.00	1.00	6.25	1.75	5.00	.50	5.00	1.50	5.00	1.00	5.25	.88
5.50	1.25	6.00	1.50	7.50	.50	5.00	1.00	6.25	1.75	6.00	1.00	7.50	.50
3.33	1.03	4.38	1.25	5.25	1.13	3.96	1.20	5.21	1.51	5.42	1.30	5.21	1.27

B. WORDS.

Immediate Recall			*Recall after Forty-eight Hours.*		
Stand.	Two Var.	Four Var.	Stand.	Two Var.	Four Var.
7.2	7.00	6.2	2.94	3.40	1.69

syllable individualized the syllable and was likely to fix it. Thus one subject said paradoxically that the syllables that he didn't get in immediate recall were the ones he got in the test for permanence.[1] For a while white type on white cardboard individualized and fixated its syllables more than colors or grays, simply because it was difficult to see. A doubt as to the identity of a letter, after being settled, was certain to fixate the syllable concerned.

If meaning is a kind of variety which persons naturally seek, as the work with nonsense syllables and words indicated, it should be susceptible to measurement. A series of twenty adjectives, and another of twenty short sentences were given to five subjects. The adjectives were:

Fat, humble, young, happy, broad, distracted, violent, privileged, sleek, reversed, cautious, immediate, ideal, polite, cold, gabled, serene, imaginative, various, trifling.

The sentences were:

Mammoth Cave is a wonderful place. Cats are not very teachable. He gave a prodigious sniff. The naval gunner is often a noble fellow. Chicago is a windy city. Genteel is a word seldom used today. Damp weather is bad for rheumatism. The need of protecting our industries is a worn argument. The mistletoe is a parasitic plant. Dogs are sociable companions for men. The theatre is potent for good as well as evil. Gambling is expensive. The steamer hit the dock a hard bump. This thread is rotten. Parks at public expense are easily justifiable. Granite is a handsome building stone. The lake is rough. The Japanese are a small race. Is abusive language ever justifiable? The owner of the horse gave a sarcastic smile, and declined the offer.

The subjects were allowed two minutes in which to study each of the series, which were given them in typewritten form.

[1] The series were shown again between immediate recall and the test for permanence See IV below.

Following directions they did not run together successive terms into larger units, and tried not to expand words into phrases or sentences. They were required to read each list through at least once. In the test for immediate recall and for retention after twenty-four hours they were required to give only the substance of the sentences, but the words verbatim. *They recalled an average of 12.8 words and 11.6 sentences in immediate recall, and 7.6 words and 7 sentences after twenty-four hours.* One of the five did worse in the sentences than in the words, the other four did as well in one as in the other. The subjects said it was difficult to keep the words from arousing mentally a thought-situation which expressed in language would have been one or more sentences. Yet it is not to be inferred that the two lists became equivalent. The *tendency* existed in that direction, and the attempt to inhibit it was partially a failure. The difficulty of controlling the material led to its discontinuance. Perhaps the significant feature, aside from the tendency toward expansion mentioned, is the fact that *the sentences are remembered as well as the words.*

Numbers are a material apparently difficult to read connected thought into, especially when given in extended series. They seem at times not very far from a dead level of monotony. Yet they may be vivified by associated material. Three series of each of the following two kinds were given: on the one hand series of two-place numbers, seven numbers in a series; on the other hand three series of similar numbers and beside each a biographical fact from the Renaissance period of Italian history. The facts were varied and some were striking. One of the series of numbers and facts was as follows:

Series III.

51 A sculptor.
93 Famous for an impromptu oration in Latin congratulating the Emperor Frederick III on his coronation.
14 A merchant of Pisa. Introduced the Arabic notation into European commercial life.
47 A monk.
26 Naples.

79 An instance of the revival of oratory. Funerals, marriages and installations of bishops were among the occasions of his efforts.

85 A bishop.

It was expected that the numbers without facts would be learned in less time than those accompanied by facts, but it was thought that the latter might be retained better. Two new series were given each week, one of each kind. Typewritten cards each containing a series were given the subject, one at a time. In the case of the numbers without the facts he memorized the list as rapidly as possible, the time record being kept by the operator with a stop watch. As soon as the subject thought he could give the list correctly he tried. If he failed, the learning process was resumed, and this continued until he gave the list correctly. The next day the series learned on the previous day was tested, and if an error was made, that series was relearned, and so on until the subject held the series correctly for 24 hours. This was the standard of learning up to which the series were brought before they were dropped. With no subsequent renewings they were tested for permanence of retention seven days and again thirteen days after the completion of learning. The series of numbers and facts were learned in the same way, except that in the tests the subject was required to give the substance of the facts with their appropriate numbers. We refer here to the learning process.

The results are given in Table 2. The first half gives the total learning times in minutes and seconds. 3:31 means 3 mins. 31 secs. In the second half, in which the recall is given, the figures indicate the number of numbers, or numbers and facts which were correctly recalled. Seven would be a perfect score for a series. No credit was allowed for partially correct numbers, or for numbers or facts apart from their correct coupling. Several cases where the recall could not be secured are marked by dashes in the table.

The numbers alone are learned in less than one-half the time taken by the numbers and facts, and are retained quite a little better.

This ended our experiments with language materials. We may summarize them as follows: Typographical variations

TABLE 2. *Renaissance Series.*

LEARNING TIMES.

Subjects.	NUMBERS.			NUMBERS AND FACTS.			AVERAGES.	
	I.	II.	III.	I.	II.	III.	Nos.	Nos. and Facts.
McP.....	3 : 31	1 : 50	2 : 39	9 : 15	7 : 30	6 : 26	2 : 40	7 : 44
G.....	: 57	1 : 43	1 : 23	10 : 15	8 : 11	9 : 37	1 : 21	9 : 21
H.....	7 : 17	1 : 36	3 : 28	7 : 50	4 : 41	5 : 25	4 : 07	5 : 59
J.....	2 : 40	3 · 27	3 : 49	10 : 28	10 : 09	12 : 24	3 : 19	11 : 00
L.....	6 : 18	5 : 20	3 : 42	9 : 36	6 : 21	7 : 06	5 : 07	7 : 41
F.....	4 : 26	3 : 51	3 : 23	8 : 00	6 : 35	5 : 05	3 : 53	6 : 33
Av.....	4 : 12	2 : 58	3 : 04	9 : 14	7 : 15	7 : 41	3 : 25	8 : 03

NUMBER OF TERMS RECALLED.

	AFTER SEVEN DAYS.						AFTER THIRTEEN DAYS.					
	Numbers.			Nos. and Facts.			Numbers.			Nos. and Facts.		
	I.	II.	III.	I.	II.	III.	I.	II.	III.	I.	II.	III.
McP...	7	4	7	7	1	6	5	0	7	3	1	5
G.....	7	4	2	7	1	2	3	1	5	5	0	2
H.....	3	6	7	6	4	5	3	5	–	5	3	–
J.....	1	2	0	2	4	7	0	0	–	0	4	–
L.....	1	4	7	3	1	4	1	2	7	2	1	4
F.....	5	5	5	3	2	2	4	3	5	1	1	2
Av.....	4	4.2	4.7	4.7	2.2	4.3	2.7	1.8	6	2.7	1.7	2.3

AVERAGES.

	Numbers.	Numbers and Facts.
After seven days.....	4.3	3.7
After thirteen days.....	3.2	2.4

are at first a strong aid in retaining nonsense syllables, but in the course of two and a half months the advantage of series varying in this way is lost, because of improvement of the ordinary series through practice. With words the typographical variations are of no aid whatever. The meaning variation

is far more important and is the kind of variation relied on. The results have an interesting bearing on the theory of advertising and printing. Our own conclusion is that if typographical variations have any value here for memory they must offer a constant novelty. *Mere variation* without a very considerable amount of newness is of no aid. If there is to be simply change from one familiar variation (or even new combination of familiar variations) to another, then the variation in the sense is the more attractive and influential, in fact the only thing that is influential. This may tax the printer rather severely, but it is some encouragement to those who depend on the content of their advertisements, rather than on the form.

When mechanical variations are left and the attempt is made to secure variety through meaning, the first part of our results are positive, the second part indecisive. Sentences are as well remembered as words, when the learning time is long enough to comprehend both. Binet and Henri and others had already shown this, but our lists of words and corresponding sentences were much longer than theirs. A still further increase in the length of the selections would without doubt show the same result. The negative results of our experiments with numbers and biographical facts are to be interpreted as a superiority of preformed associations over associations required to be formed during the learning process. In the series of numbers without facts the subjects could not prevent the numbers from suggesting associations from their past experiences. 57 became 57th St., 65 the age of a member of the family, etc. Dates, too, were suggested by some of the numbers. The impossibility of controlling the associations led to the discontinuance of the use of numbers. A similar difficulty has been mentioned already in connection with the use of lists of words.

In the next section we propose to make a brief digression to discuss a question of nonsense syllable technique. It may be omitted without detriment to the comprehension of the main problems under consideration.

IV. ON METHODS OF LEARNING AND TESTING NONSENSE SYLLABLES.

The method of learning the series of nonsense syllables in III consisted in giving the various series to be compared equal numbers of repetitions, extending the learning process over two days, and securing an immediate recall on the first day and a recall after 24 hours on the third day. On the first day the subject was given 2 repetitions of a series in practically immediate succession and then tested for immediate recall, the test being the quantity of syllables recalled and the cue, simply the direction to begin. This was followed by 5 repetitions. The next day the subject spent from 5 to 10 minutes, the exact amount determined by the operator and depending on the number of series, in recalling, as before, as many syllables as he could. Placing in the proper series was understood to be not essential. This was followed by 3 repetitions. On the third day without further seeing the series and with no other cue than an enumeration by the operator of the varieties of series which had been given, the subject again wrote as many syllables as he could recall. There was no time limit on this test. The intervals between repetitions and series were properly regulated, and kept constant. Reviewing was permitted during the progress of a repetition but not between repetitions. The rate was 50 beats of the metronome per minute with an exposure on every alternate beat. The large percentages of recall in the tables speak in favor of the workableness of the method.

The method has advantages over several of those currently in use. In the Ebbinghaus method of entire learning and relearning, if the series are short, for example nine syllables, the repetition is too gross a measure to detect small differences. The difference of 1 repetition between the 4 and the 5 (let us say) necessary for perfect immediate recall of two nine-syllable series may represent the recovery of a single consonant, or 18 seconds of hard work on the part of the subject. Our method gets over this difficulty by giving a fixed number of repetitions, the same for the various types to be compared and

measures the difference by the percentages of recall. The method of successes, used by Müller and Pilzecker and many others, also has this advantage, but has one objection that in our opinion is fatal to it for many subjects, in fact most subjects. It encourages word associations. The two syllables constituting a couplet are likely to suggest to a subject single words or phrases which form a unity in his past experience and serve here to link the two syllables together. Gan muc suggests gander mud, laj gul suggests large girl. The difficulty is a well-known one and is treated by Ebbinghaus in his Grundzüge, p. 676. It is present to some extent in the non-couplet methods, but the couplet methods (Treffermethoden) greatly increase the frequency of occurrence. In an investigation made some years ago it was demonstrated that couplets in which word associations of this sort occurred were better retained than the rest of the series, and the superiority was measured.[1] Under certain conditions, which do not concern us here since they were the same for both kinds of material, couplets in which word associations did not occur had a recall of 63 per cent correct after one day, which sank to 19 per cent after fifteen days more. In contrast with this, couplets in which word associations occurred had a recall of 82 per cent correct after one day, which sank only to 64 per cent after fifteen days more. The results were based on six subjects and 64 couplets altogether, of which somewhat the larger share were couplets in which no word associations occurred. If the couplets in which word associations occurred were thrown out or separated, there would be no objection to this method, but the waste of effort is great, and it has never been done to the writer's knowledge, except in the investigation just quoted.

Our method makes an economical use of the experimenter's and the subject's time by using short series and distributing the learning over two days. By making the amount recalled, instead of the number of repetitions required to learn, the means of measurement, it measures small differences. It keeps the word association factor at a minimum. If it has an objec-

[1] Peterson, H. A. Recall of Words, Objects and Movements. Psych. Rev., 1903, Mon. Sup., iv, p. 232.

tion, it is the possibility that the recall after the last twenty-four hours may not be enough for purposes of comparison. This is doubtless true of some subjects. In the foregoing experiments, P was such a subject. This objection would not hold for the five other subjects employed by us, with all of whom the recall was sufficient for comparison.

V. EXPERIMENTS WITH PLANE AREAS

1. Adding Variations to a Material Containing Little Variation

The next material selected was both simple and highly similar internally. Different shades of gray were associated with their spatial positions on a cardboard area. Four series were given, the first of which varied in shades of gray only, the second in gray and the color of the center, the third in gray and the size of the different presentations of the series, and the fourth in gray and the shape of the presentations. The same seven grays were used in all four series. They were the Hering papers Nos. 1, 2, 5, 8, 19, 35 and 49. Each series had seven terms or presentations in it, and the shades of gray ranged from black to white with about equal differences between nearest shades. All seven terms were exposed simultaneously. The gray sizes may be given as a sample series. They were, from left to right as follows:

Oblongs, height twice the width. Dark gray 128 sq. cm.; very light gray, 40.5 sq. cm.; white, 60.5 sq. cm.; black, 2 sq. cm.; medium gray, 84.5 sq. cm.; light gray, 8 sq. cm.; very dark gray, 24.5 sq. cm.

The form-varying series is shown in the plates in the Appendix.[1] All of the series except the one which varied in size were composed of terms whose areas were 50 sq. cm., and even the size series had the same total area as the other three, viz: 350 sq. cm. The color-varying series were made by pasting small oblongs of color 1.5 cm. wide and 3 cm. high on the gray oblongs, themselves 5 cm. wide and 10 cm. high. Each of the series was mounted on a sheet of white cardboard 22 × 28 inches, with the longer side as the base.

[1] Gray Forms.

Conceivably the ease of memorizing such series would depend greatly on the order of succession of the terms. However, inasmuch as one of the purposes of the investigation was to obtain information on this point, aside from certain obviously easy arrangements, it was thought best to determine it by chance. The following cases embrace all exclusions: (1) in sizes, a continuous increase followed by a continuous decrease, or vice versa; or a continouus increase alone or decrease alone; (2) in shades of gray, or violet (the latter series to be described later) a continuous change from black to white or vice versa, or from red to purple or vice versa; (3) in grays, colors, and sizes, the same arrangement as some previous series. This rule resulted probably in less uniformity of material, but at least was free from the influence of unconscious subjective favoring.

To increase the number of series a group of four series was next made which in all respects was similar to the gray group except that shades and tints of violet were used. The colors in the series with colored centers, and the shapes in the form-varying series were different from what had been used in the gray group. The shapes are given in the plates. The same sizes were used in the size-varying series as in the grays, but to diminish interference from the gray sizes they were right triangles. The effort was made to secure violets which would be about as difficult to discriminate as the grays. The ones selected were: blue violet, violet, violet tint 1, red violet, red violet tint 1, violet red. To these purple was added. The grays were learned the first week and the violets the second week.

The method of learning the series was the same as the one used in experiments with numbers and biographical facts. We shall describe the process in its several steps. When the shutter opened the subject began to learn the series. As soon as he thought he had mastered it, so that he could give it the next day, he gave a signal, whereupon the shutter closed. The subject then turned to a small table on his right, uncovered a set of unmounted duplicates of the series, and tried to arrange them in the right order. As soon as he had arranged the series as best he could he gave a signal, whereupon the operator at once removed the duplicates. If the attempt was unsuc-

cessful, the duplicates were returned bunched and covered, the series was again exposed and the learning process resumed, and again tested, till the series had been perfectly arranged. The lengths of exposure were kept with a stop-watch.

Where more than one exposure of the series a day was necessary, the lengths of the exposures were recorded separately, and the number of arrangements which the subject required. The next day the series given on the previous day were tested again by use of the duplicates. If the arrangement of any series contained an error, that series was again exposed for such a length of time as the subject required, and again tested. The subject could not omit the arranging if he desired. If he showed by his preliminary arrangement on the second day that he had held the series perfectly for a day, it was not again shown. Having been brought up to the standard, the series was dropped for thirteen days, when the retention test took place. The learning was usually completed by the third day. The purpose of all this was to bring the series up to a point of immediate fixation that would insure enough recall after two weeks for purposes of comparing the different types of series. The test which was given after thirteen days consisted in the subject's again arranging the series. No introspections were allowed and no comments could be given till after this test, because such introspections or comments would fixate the series, and do it unevenly. For introspections our main reliance was on series given especially for this purpose and not recorded in the tables. Reviewing after an arrangement had been made was not allowed. Having arranged the duplicates the subject who followed instructions dismissed the series from his mind. The intervals between exposures and between series were regulated.

Toward the end of the investigation a series of experiments was carried out upon the same subjects with similar material for the purpose of determining the value of the practice of allowing the subject to arrange. The details are given on pp. 65–7, which may be profitably read at this point. The method employed consisted in giving parallel series as nearly equal in difficulty as possible. In one-half of them the learning was

carried on solely by looking at the series through the aperture. The other half were given the same lengths of exposure and in addition the subject was allowed the usual arrangement of duplicates. The recall after the lapse of a week gave the relative efficiency of the two methods of learning, and by subtracting the total recall of all the series in which there was no arranging from the total recall of the series in which arranging had been allowed, the value of the arrangements alone was obtained. Since a given number of arrangements produced a certain number of units of recall and a given amount of time of exposure produced a certain number of units of recall, by reducing both to the amounts of each necessary to produce one unit of recall it was possible to find for an arrangement its equivalent in minutes and seconds of learning time. With this average value, one for each subject, the arrangements were converted into learning time and added to the amounts actually consumed by a subject in looking at the series through the aperture. Thus our two time measurements were reduced to one.

This in brief was our method. In one way it lacked exactness, namely, in the distribution of the learning periods over varying numbers of days. But in another way it had exactness. By making the subject the judge of the time necessary for learning, learning times were secured which minute for minute represented equivalent degrees of effort. A comparison of the subjects' speed of learning given on page 64 will convince any one of the impossibility of getting accurate results when giving the same exposure intervals to all subjects and for all materials. The difficulty of appraising the value of the tests allowed the subjects during learning—a difficulty which has been felt by many experimenters on memory—was satisfactorily solved by the method described. Again, one of the principal advantages of our method is the opportunity it affords for studying different types of learners. The fact that one series was learned more thoroughly than another, that the subject could not judge accurately his ability to hold a series for a day, did not introduce error into the results if the assumption be granted that recall after thirteen days is in proportion to the thoroughness of the

original mastery. Any one who doubts this can find evidence in our tables in the form of mean variations.

The use of duplicates as a means of testing was adopted to avoid as far as possible the inequalities which would be introduced into the material by the ready presence or absence of names. Lehmann[1] and Angell,[2] among others, have shown that colors which can be readily named are better discriminated and remembered than those which cannot be. Again, the desire of the author was to guide the whole investigation away from language and into retention and learning of the material presented. The initials of the colors could be made into a mnemonic word and thus remembered, and similarly sizes and forms. There was no desire to experiment in the linguistic field here, and the subjects were repeatedly turned in the opposite direction and, judging by their own testimony, with success. The part played by language is discussed on p. 47 in connection with methods of learning.

The results of the gray and violet sets are given in Table 3. The learning times are given in minutes and seconds and arrangements; for instance, F. learned the grays in 4 mins. 1 sec. and 2 arrangements. The abbreviation 'arrs.' means number of arrangements which the subject required in bringing the series up to standard. The recall in the second half of the table is based on a method of scoring which briefly was this. Perfect score for a series: 14. Each term allowed 1 for correct absolute position (left end, or second from there, etc.) and 1 for correct relative position (having the correct terms on both sides of it). One-half for next-to-correct absolute position, e. g., 4th or 6th from left end instead of 5th. One-half for one neighbor correct, and one-quarter for each neighbor correct but on the wrong side. Terms whose relative positions are made incorrect by the errors of the other terms lose no credit themselves.

The table shows that when the shades of gray and violet are varied in form and size, or when they are given colored centers, there is a marked reduction in the learning times and a large

[1] Phil. Studien, V, 1889, p. 96.
[2] Phil. Studien, XIX, 1902, p. 1.

TABLE 3. *Areas varied in Color, Size and Form.*

A. Learning Times.

SUBJECTS.	GRAYS.		G. FORMS.		G. SIZES.		COL. GRAYS.	
	Time.	Arrs.	Time.	Arrs.	Time.	Arrs.	Time.	Arrs.
F.	4 : 01	2	2 : 42	2	3 : 22	2	3 : 30	2
Mc.P.	5 : 10	7	: 54	2	1 : 02	5	2 : 01	4
G.	1 : 48	8	: 30	3	: 52	7	: 46	2
H.	1 : 51	2	: 43	2	1 : 38	4	2 : 15	2
J.	4 : 24	3	1 : 12	2	1 : 47	2	2 : 20	2
L.	3 : 34	5	1 : 25	2	1 : 37	4	2 : 21	4
Av.	3 : 28	4.5	1 : 14	2.17	1 : 43	4	2 : 12	2.67

	VIOLETS.		V. FORMS.		V. SIZES.		C. VIOLETS.	
F.	4 : 34	3	: 55	2	1 : 42	2	1 : 30	2
Mc.P.	8 : 00	10	: 43	2	1 : 47	6	1 : 46	4
G.	1 : 45	7	: 54	2	1 : 19	4	1 : 23	4
H.	2 : 51	6	: 35	2	1 : 09	2	1 : 05	2
J.	4 : 41	4	: 39	4	1 : 13	2	1 : 50	2
L.	: 47	2	: 29	4	1 : 25	4	2 : 22	6
Av.	3 : 46	5.33	: 43	2.67	1 : 26	3.33	1 : 39	3.33

B. Recall after Thirteen Days.

	GRAYS.	VIOLETS.	G. FORMS.	V. FORMS.	G. SIZES.	V. SIZES.	COL. GRAYS.	COL. VIOLETS.
F.	6.50	4.00	6.00	14.00	4.00	5.00	11.50	14.00
Mc.P.	4.00	6.00	8.75	6.00	14.00	6.50	8.50	9.00
G.	9.50	6.00	4.00	14.00	6.25	6.00	4.00	4.00
H.	4.00	6.50	9.00	11.50	4.00	7.25	10.00	10.50
J.	5.00	4.00	7.00	14.00	4.00	8.25	4.00	4.00
L.	4.00	9.00	11.50	14.00	4.00	4.00	6.50	4.75
Av.	5.50	5.92	7.71	12.25	6.04	6.17	7.42	7.71

increase in recall. If the arrangements be converted into learning times, and an average be taken of the gray and violet sets together, *the addition of a form variation reduces the learning time 68 per cent and increases the recall 75 per cent. The addi-*

tion of a variation in size reduces the learning time about 50 per cent and increases the recall 7 per cent. The addition of a variation in color reduces the learning time 45 per cent and increases the recall 32 per cent. Form is therefore the most effective variation, color next and size the least. All six subjects benefit by all three variations. The improvement is extremely marked and very general.

The question arises whether the variations in color, form and size were not easier to associate with position than the grays and violets, and were therefore taken as the thing to be learned, the grays and violets being neglected. In other words, was the improvement due to substitution rather than to increasing complexity? Did the subjects use the shades of gray and the violet colors at all? The likelihood that this did occur is increased by the fact that interference was likely to enter from the connection of the same shades of gray with different positions in different series, and the same for violets. The opinion of the subjects on this point is of value. They said that the grays (or violets) and their added variations formed unities before the learning process was completed, but that the variations added to the grays or violets, being the more easily discriminated, were the main reliance in learning and recalling.

The experiment does not tell us whether the combination of two variations, in themselves about equal in discriminability, would be more readily associated and better retained than either alone. For example, the table shows that shades of gray and violet colors without additional variations were about equal. Would their combination result in a learning time and retention better than either alone? While the experiment was not performed, there is no doubt that at this low level of variation it would.

To summarize the present situation in the solution of our problem: in the shades of gray or shades and tints of one color, a material has been found which has a rather large amount of sameness and simplicity about it, and still is free from the preformed associations which hindered the linguistic experiments. So far as this material is concerned the experiments

just completed answer the first part of our thesis. Adding variations improves both the learning times and retention of all the subjects by large amounts, the precise amount differing with different variations. The next step is to try adding variations to materials similar in their general character to grays and violets, but containing in themselves more variety and complexity.

2. *Adding Variations to More Varied Materials.*

In this set of experiments there was not only an ascent to more varied bases than grays and violets, but there was also an effort to add variations that were equal or less in discriminability than the bases to which they were added. Color, form and size were suspected of fulfilling these conditions. Twenty-four series of six different kinds were made.

i	4 series of colors	iv	4 series of colored sizes
ii	4 series of sizes	v	4 series of colored forms
iii	4 series of forms	vi	4 series of colored forms of different sizes.[1]

The twelve series on the left aim to find the value of color, size and form separately; the twelve on the right, their value in combination. Together they should answer such questions as the following: Suppose it should result that colors and sizes each by themselves are learned about equally well. Are series which vary in both ways simultaneously (colored sizes) learned more quickly, and retained better, or not? If better, it can be due only to the increase in complexity and resulting differentiation, and not to substitution. In the same way the last two groups on the right may be compared with the last on the left.

The general plan of these series differed from that of the series of grays and violets in one important respect. The colored sizes, for example, did not add a size variation to the colors of the *previous* color series, but, as far as the realm of colors

[1] It will be found helpful in the comprehension of the following general description to read for illustrative purposes the construction of a few typical series in the Appendix, pp. 74–80. The Bradley papers were used.

offered variety, combined size with colors *not heretofore used*. Similarly when in the third, fifth and sixth groups of series above enumerated, form became a base, the *same* forms were not used over again, as was the case with the shades of gray and violet, but new forms were found. This change was in the interest of a reduction of interference. The principle could be carried out most fully in the case of forms, less completely with colors, and still less with sizes. Our guiding idea was to use all the wealth of variety which each realm, color, size and form afforded. Our attitude was therefore an entirely practical one. Of the 76 different colors used in this set and in the gray and violet sets, 38 were used only once, 18 twice, 14 three times and 6 four times. Of course the subjects did not discriminate in memory nearly as many colors. Of the 78 different shapes used in the investigation with these subjects, 48 were used only once, 26 twice and 4 three times. The repetition of forms was confined entirely to two series in each of the form-varying groups, namely, Forms I and II, Colored Forms II and III, Colored Forms of different Sizes III and IV, and these six series were composed wholly of forms which had been used once before. Thus there was a restricted area within which the effect of repeating forms could be observed. It is essential to note that in respect to this feature *the three form-varying groups were on an equal footing*, for otherwise they could not be compared. Wherever a form was used again, it was altered markedly in size and color. With series of sizes the limitations of the apparatus and work-room made the variety small. In certain extra series not included in the results we tried the effect of larger sizes, but in the size series given in the tables the aggregate area of the seven terms of a series was in every case 350 sq. cm., which was the same as for all the other series. Now within this limit the number of sizes which are favorable for inter-term discrimination is relatively very small. We found the best showing for sizes could be made by restricting the choice to about twelve sizes, which we did. The other devices used for reducing interference were to give each series which did not vary in form or color a distinctive color and form of its own; similarly each series of

colors had a distinctive series-form, etc. The series were mounted on white cardboard, 14 × 28 inches, all the terms resting on a horizontal base line. A full description of all the series used, including some extra ones not reported in the tables, but used in the analysis of errors to follow later, will be found on pp. 74–80. A few further remarks here will give a sufficient account of the series for most purposes.

As it was the intention to compare the results of pure sizes and colored sizes it was necessary to keep them equally discriminable in size. This was done by using the same sizes (though not in the same shapes) in both. Thus two series of pure sizes and two of colored sizes increased in area in the geometrical ratio of 2.77 beginning with a minimum area of .5 sq. cm. The other two series of sizes varied by irregular ratios which decreased somewhat toward the largest terms, but they were repeated in the other two series of colored sizes. The order in which the terms of the series were arranged was determined by chance, excluding the exceptions made on p. 28. The twelve series varying in form are reproduced in the plates on a reduced scale and need little further description. All of the forms in the third and fifth types were of the same area, 50 sq. cm. The guiding ideas in the selection of forms were to keep within the three classes: conventional geometrical figures, very simple decorative designs, and relatively meaningless forms. The word relatively is emphasized, for those subjects who looked for meaning in forms usually found it,—meaning of some sort. The forms vary from simple to somewhat complex, but there are no intricate forms. Considerable care was taken to make the series as nearly equal in difficulty as possible, with what success will appear in the sequel.

These twenty-four series were given in the same way as the gray and violet sets. The subjects worked on three, and if necessary to learn the series four, successive days each week; on one or two occasions, five days. To distribute the effects of practice and interference, the six types were learned concurrently, although the Roman numerals I, II, III and IV do not indicate the order in which the series were learned. All the conditions not specifically mentioned were the same as in the gray and violet sets.

TABLE 4. *Areas varied in Color, Size and Form. Associated with Spatial Position.*

A. LEARNING TIMES.

Colors.

	I.		II.		III.		IV.		AVERAGES.	
	Time.	Arrs.	Time.	Arrs.	Time.	Arrs.	Time.	Arrs.	Time.	Arrs.
G.....	:53	4	:39	2	:35	5	:30	4	:39	3.75
H.....	:55	4	:44	2	:41	2	:51	4	:48	3.00
J.....	1:47	4	1:04	2	2:21	5	:43	2	1:29	3.25
L.....	1:01	1	:41	4	1:25	5	1:02	3	1:02	3.25
N.....	:38	4	:44	3	:15	4	:24	2	:30	3.25
R.....	:24	2	:36	2	:38	5	:19	4	:29	3.25
Av.....	:56	3.17	:45	2.50	:59	4.33	:38	3.17	:50	3.29
Sizes.										
G.....	:36	6	:33	2	:36	4	:41	5	:37	4.25
H.....	:26	2	:20	2	:46	6	:33	4	:31	3.50
J.....	:35	2	1:40	4	1:31	4	1:02	4	1:12	3.50
L.....	:50	2	:39	2	:47	4	:43	4	:45	3.00
N.....	:34	8	:14	4	:49	6	1:04	8	:40	6.50
R.....	:14	2	:22	4	:31	4	:29	4	:24	3.50
Av.....	:33	3.67	:38	3	:50	4.67	:45	4.83	:42	4.04
Forms.										
G.....	:26	2	:41	2	:21	2	:27	2	:29	2.00
H.....	:38	2	:50	2.	:30	2	:23	2	:35	2.00
J.....	:31	4	:35	2	:27	2	:38	2	:34	2.50
L.....	:39	2	:40	2	:31	2	:41	2	:38	2.00
N.....	:45	3	:21	2	:12	2	:10	2	:22	2.25
R.....	:24	4	:18	4	:13	3	:18	2	:18	3.25
Av.....	:34	2.83	:34	2.33	:22	2.17	:26	2	:29	2.33
Colored Sizes.										
G.....	:46	4	:34	2	:23	4	1:05	8	:42	4.50
H.....	:59	4	:40	2	:29	4	1:12	6	:50	4.00
J.....	2:05	4	:39	2	:45	2	1:33	4	1:16	3.00
L.....	1:23	4	:40	4	1:04	5	:51	4	:60	4.25
N.....	:52	4	:27	2	:15	4.	:26	5	:30	3.75
R.....	:59	4	:35	4	:17	5	:17	4	:32	4.25
Av.....	:71	4	:36	2.67	:32	4	:54	5.17	:48	3.96

Colored Forms.

	I.		II.		III.		IV.		AVERAGES.	
	Time.	Arrs.	Time.	Arrs.	Time.	Arrs.	Time.	Arrs.	Time.	Arrs.
G.....	:24	2	:19	2	:33	4	:25	4	:25	3.00
H.....	:22	3	:36	2	:24	2	:22	4	:26	2.75
J.....	:45	2	1:15	5	:37	2	:22	2	:45	2.75
L.....	:35	2	:45	2	:38	3	:38	3	:39	2.50
N.....	:16	2	:13	2	:16	3	:15	2	:15	2.25
R.....	:15	3	:13	2	:11	2	:15	2	:14	2.25
Av.....	:26	2.33	:34	2.50	:27	2.67	:23	2.83	:27	2.58

Colored Forms of Different Sizes.

G.....	:20	2	:13	2	:41	2	:43	2	:29	2.00
H.....	:48	2	:46	2	:46	2	:30	2	:43	2.00
J.....	:43	2	1:10	4	:34	2	:38	2	:46	2.50
L.....	:28	2	:52	4	:30	2	:35	2	:36	2.50
N.....	:20	2	:16	2	:25	4	:15	2	:19	2.50
R.....	:16	2	:16	2	:14	2	:14	4	:15	2.50
Av.....	:29	2	:36	2.67	:32	2.33	:29	2.33	:31	2.33

B. RECALL AFTER THIRTEEN DAYS.

Colors.

	I. Recall.	II. Recall.	III. Recall.	IV. Recall.	AVERAGES. Recall.
G.....	5.25	11.50	7.00	8.50	8.06
H.....	7.50	8.00	4.50	7.25	6.81
J.....	8.00	6.75	4.50	6.00	6.31
L.....	4.50	7.00	6.75	6.00	6.06
N.....	6.00	14.00	7.50	4.00	7.88
R.....	5.50	8.25	8.00	6.75	7.13
Av.....	6.13	9.25	6.38	6.42	7.05

Sizes.

G.....	7.00	4.00	4.00	11.50	6.63
H.....	14.00	6.00	14.00	5.25	9.81
J.....	4.00	5.00	7.00	8.25	6.06
L.....	11.50	6.50	8.00	6.50	8.13
N.....	5.25	4.50	4.50	7.00	5.31
R.....	5.00	4.00	4.00	4.00	4.25
Av.....	7.79	5.00	6.92	7.08	6.70

Forms.

	I. Recall.	II. Recall.	III. Recall.	IV. Recall.	AVERAGES. Recall.
G.	11.50	4.00	6.75	8.50	7.69
H.	14.00	8.00	5.25	11.50	9.69
J	11.50	4.00	11.50	11.50	9.63
L.	11.50	6.75	10.00	9.00	9.31
N.	11.50	7.00	10.50	11.50	10.13
R.	8.25	5.00	6.00	8.00	6.81
Av.	11.38	5.79	8.33	10.00	8.88

Colored Sizes.

G.	5.00	4.00	6.00	10.50	6.38
H.	6.50	5.50	6.25	14.00	8.06
J.	11.50	6.50	5.50	8.50	8.00
L	5.00	5.25	4.00	4.00	4.56
N.	4.00	8.25	8.50	10.50	7.81
R.	8.25	9.25	10.00	6.00	8.38
Av.	6.71	6.46	6.71	8.92	7.20

Colored Forms.

G.	8.00	6.50	5.00	4.75	6.06
H.	14.00	14.00	6.75	10.50	11.31
J.	7.50	14.00	5.50	6.25	8.31
L.	4.00	6.25	5.75	7.00	5.75
N.	11.50	14.00	6.00	10.50	10.50
R.	14.00	5.50	9.00	14.00	10.63
Av.	9.83	10.04	6.33	8.83	8.76

Colored Forms of Different Sizes.

G.	9.00	4.75	10.00	4.25	7.00
H.	10.50	8.50	14.00	4.00	9.25
J.	8.00	14.00	10.50	6.75	9.81
L.	9.00	11.50	4.00	6.25	7.69
N.	9.00	5.75	10.50	10.00	8.81
R.	11.50	5.00	11.50	6.50	8.63
Av.	9.50	8.25	10.08	6.29	8.53

TABLE 5. *Areas varied in Color, Size and Form associated with Position. Recall per Ten Seconds.*

G.

Series.	COLORS.		SIZES.		FORMS.		COL. SIZES.		COL. FORMS.		C. F. d. S.	
	Rec.	M.V.	Rec.	M.V.	Rec.	M.V.	Rec.	M.V.	Rec.	M.V.	Rec.	M.V.
I.	.719	.764	1.060	.052	3.194	1.081	.757	.258	2.353	.705	3.000	1.312
II.	2.347	.864	.930	.182	.784	1.329	.909	.106	2.241	.593	1.439	.249
III.	1.167	.316	.714	.398	2.177	.064	1.395	.380	.943	.705	1.639	.049
IV.	1.700	.217	1.742	.630	2.297	.184	1.000	.015	1.055	.593	.675	1.013
Av..	1.483	.540	1.112	.316	2.113	.665	1.015	.190	1.648	.649	1.688	.656

H.

I.	.718	.104	2.762	1.285	2.233	.564	.600	.202	2.369	.486	1.444	.115
II.	1.164	.342	1.342	.135	1.071	.598	.850	.048	2.306	.423	1.202	.127
III.	.685	.137	1.166	.311	.960	.709	.797	.005	1.386	.497	1.938	.609
IV.	.722	.100	.637	.840	2.411	.742	.959	.157	1.470	.413	.731	.598
Av.	.822	.171	1.477	.643	1.669	.653	.802	.103	1.883	.455	1.329	.362

J.

I.	.412	.065	.506	.076	.982	.146	.542	.062	.846	.036	.924	.075
II.	.625	.148	.267	.163	.509	.619	.783	.179	.760	.050	.891	.108
III.	.180	.297	.393	.037	1.620	.492	.620	.016	.682	.128	1.353	.354
IV.	.690	.213	.554	.124	1.402	.274	.472	.132	.953	.143	.827	.172
Av.	.477	.181	.430	.100	1.128	.383	.604	.097	.810	.089	.999	.177

L.

I.	.634	.029	1.643	.531	1.949	.322	.406	.057	.727	.164	1.875	.523
II.	.864	.201	1.102	.010	1.125	.502	.656	.193	.962	.071	1.597	.245
III.	.500	.163	.919	.193	1.960	.333	.351	.112	.846	.045	.800	.552
IV.	.652	.011	.783	.329	1.475	.152	.440	.023	1.029	.138	1.136	.216
Av.	.663	.101	1.112	.266	1.627	.327	.463	.096	.891	.105	1.352	.384

N.

I.	.689	.412	.394	.083	1.402	.875	.394	.652	2.825	.246	2.013	.174
II.	1.728	.627	.714	.238	1.532	.745	1.289	.243	3.713	1.134	1.413	.426
III.	1.165	.064	.366	.110	2.861	.584	1.304	.258	1.132	1.447	1.411	.428
IV.	.821	.280	.428	.047	3.314	1.037	1.197	.151	2.645	.066	2.519	.680
Av.	1.101	.346	.476	.120	2.277	.810	1.046	.326	2.579	.723	1.839	.427

R.

I.	1.250	.056	1.470	.655	1.289	.124	.833	.320	3.111	.235	3.194	.902
II.	1.473	.279	.645	.170	.862	.551	1.233	.080	1.667	1.209	1.389	.903
III.	.909	.285	.563	.252	1.395	.018	1.492	.339	2.727	.149	3.382	1.090
IV.	1.144	.050	.580	.235	2.105	.692	1.053	.100	4.000	1.124	1.204	1.088
Av.	1.194	.168	.815	.328	1.413	.346	1.153	.210	2.876	.679	2.292	.996

SUMMARY.

	COLORS.		SIZES.		FORMS.	
	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.
G.	1.483	.540	1.112	.316	2.113	.665
H.	.822	.171	1.477	.643	1.669	.653
J.	.477	.181	.430	.100	1.128	1.383
L.	.663	.101	1.112	.266	1.627	.327
N.	1.115	.347	.476	.120	2.277	.810
R.	1.194	.168	.815	.328	1.413	.344
Av.	.959	.251	.904	.296	1.705	.697

	COL. SIZES.		COL. FORMS.		C. F. d. S.	
	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.
G.	1.015	.190	1.648	.649	1.688	.625
H.	.802	.103	1.883	.455	1.329	.362
J.	.604	.097	.810	.089	.999	.177
L.	.463	.096	.891	.105	1.352	.384
N.	1.046	.326	2.579	.723	1.839	.427
R.	1.153	.210	2.876	.679	2.292	.996
Av.	.847	.170	1.781	.450	1.583	.495

The results are given in Tables 4 and 5. In part A of Table 4 the learning times are given in minutes and seconds, and arrangements; in part B the amounts recalled after thirteen days are given on the scale of 14 for perfect recall of the series.[1] In Table 5 the recall of Table 4 is recalculated by finding the equivalents, in learning times, of the arrangements, adding them to the net learning times, and then calculating the amounts recalled per ten seconds of aggregate learning time. A summary of Table 5 follows it, and a verbal summary is given last. "Rec." means recall and M. V., mean variation.

Summary of results. For reasons evident in what follows it will be necessary to consider the subjects individually. It may be well to recall the fact that we are seeking limits to the effectiveness of increasing variety, the combination being each time new, and that from the very nature of attention limits will certainly be reached. It may be well to recall also that with the less varied bases—the shades of gray and violet—all of the subjects profited very markedly by all of the added variations. But color is a more varied base than gray or violets and, to say nothing of isolated series, a dozen series of forms contains more variety than a dozen series of colors. Accordingly it may be expected that before long the subjects, according to their powers of discrimination, retentiveness, and span of consciousness and consequent ability to resist distraction, will begin to diverge. Some will reach a limit sooner than others. Under such conditions, averages of different subjects are worth little. In what follows it will be necessary to consider the memory for size and color separately as well as in combination. Two very important results shown by all the subjects in marked degree may be mentioned first, however. First, *all six subjects retain forms much better than sizes and colors.* Secondly, *all six subjects retain colored forms better than colors.* The second of these two results is comparable to the results obtained in the gray and violet set, for in both cases the variations added were much more easily discriminated than the bases to which they were added.

[1] Described on p. 31.

Subject G. Pure colors and pure sizes are retained about equally well. Colored sizes are retained at least no better than either alone, while colored forms and colored forms varying in size, in themselves about equal, are not as well retained as pure forms. G. says:[1]

> Color in colored sizes is a slight aid, but less than the natural fluctuation in ease and difficulty in passing from one size series to another. In the form-varying series, in the long run color is of no value, unless there are no peculiarities in form or size sufficient to hold the series. This seldom happens. The size variation in colored forms of different sizes may be of value on occasion.

Subject H. Pure sizes are better retained than pure colors. Colored sizes show no improvement over even the poorer of the two. Colored forms are slightly better retained than pure forms, but the series with two additions (color and size) are not as well retained as pure forms. H. says: "Colored sizes are easier to *learn* than either sizes or colors, but variations added to form are a distraction in learning. However, in recall they may confirm the arrangement after it is made." H.'s learning times in Table 4 do not confirm his remarks as to the greater ease for him of learning colored sizes. They took more time.

Subject L. Sizes are much better retained than colors. Colored sizes are more poorly retained than either sizes or colors. If the four series of each kind be arranged in order of increased retention per ten seconds of total learning time, all four colored sizes are poorer than even the corresponding *color* series. Only one of the former group is as good as any of the latter. Here the combination is actually poorer than either of the elements. Colored forms and colored forms of different sizes are also not as well retained as pure forms. L. says:

> Colored sizes are harder than colors and sizes because of conflicting methods. In colors I associate the end and middle colors with their positions, and link

[1] These opinions of the subjects were obtained in all cases after all experimenting had been completed. The subjects did not know what any of the results of the investigation were except what they may have inferred from observing themselves.

the intermediate ones with them or with each other, depending on the color associations they offer. In sizes I make groups of regularly increasing and decreasing sizes.[1] In colored sizes the color distracts me from using my size method and the size variations, from using the color method. The result is I use both. As a rule forms are easier than colored forms. *Occasionally* color is an aid, for example when the forms are closely similar. The reason for the difficulty is the same as in colored sizes, namely, conflict of habitual methods. Whether the addition of both color andsize to form is an aid I am not sure.

Subject N. Colors are much better retained than sizes,—the reverse of the two preceding subjects. Colored sizes are retained better than sizes and about the same as colors. Color alone added to form shows some gain over pure form, but the large mean variation makes the advantage uncertain. When both color and size variations are added, the result is no better than in pure forms. N. says:

The color in colored sizes makes the size stand out, but introduces a conflict of methods of learning, and resulting distraction. The result is a mixture of methods. I usually use size to fix the largest and smallest ones and color, and size to fix the intermediate ones. The variations added to form also produced distraction in learning, the forms affording sufficient variety in themselves. *The color and size variations added to forms just gave me more to notice.* However, sometimes color aids in recalling the position of a form.

With the four persons above limits were reached. With the next two, however, they were not.

Subject J. Colors and sizes are retained about equally well, and colored sizes are retained considerably better than either. If the series of each group are arranged in the order of increasing retention per ten seconds, all of the colored sizes except one series are better than the corresponding series of colors alone or sizes alone. In the case excepted the colored sizes are at least as good. Colored forms and colored forms of different sizes are not quite as well retained as pure forms, although the difference is quite small. J. says:

The element of color in colored sizes is an aid,—it gives each member in the series an individuality and thus helps to fix it in its absolute position; at the

[1] On the methods of learning pure sizes, see p. 48.

same time it tends to break the 'sky-line' schemes.[1] It is a larger factor than the natural fluctuations in ease and difficulty of different series of pure sizes, with a few exceptions. In general all three variations were aids, alone or in combination: size, because it makes a 'sky-line,'—to which also forms may contribute; color because it fixes the center, or a term left out of my series-scheme.

Subject R. Colors alone are better retained than sizes alone. Colored sizes are about the same as colors. Both colored forms and colored forms of different sizes are considerably better retained than pure forms. If the series of each group are arranged in order of increasing retention per ten seconds, all the colored forms and all the colored forms of different sizes exceed the corresponding series of pure forms. There seems to be no question that the variations added to forms are an aid to this subject. She says:

The presence of color in colored sizes is an aid because it makes the middle terms (middle in area) easier to discriminate. It does not prevent the use of the pure size method (the method used by all the subjects). The addition of color and size variations to form-varying series helps materially in differentiating similar forms both in learning and remembering.

Summary: To recapitulate,—*four subjects, G, H, L, and N, show practically no gain in retention in either of the two principal types of increased variation used here.* In quite a number of cases the recall is actually poorer with the combination. The subjects are either unaffected by the variations, finding sufficient variety in the base, or they are distracted by a conflict of methods of learning which they do not succeed in harmonizing, or by the presence of variations which they use only occasionally but cannot help noticing most of the time. *In contrast with them are the subjects J. and R. To them all the additional variations were an aid subjectively both in learning and recalling, and the tables quite decidedly bear out their introspections in the case of colored sizes with J. and colored forms and colored forms of varying sizes in the case of R.* That a type of variation should be an aid to J. and R. and still not

[1] On the method of learning pure sizes, see p. 48.

show a gain in their results is possible. It may be too small to show; or it may cause an unconscious diminution in effort. If a conflict of methods exists in colored sizes they have harmonized it. This is evident from the fact that they use a combination of both methods, retaining the 'sky-line' scheme,[1] and still using color for the terms intermediate in size, or for a term left out of the size scheme. They are not distracted by the multiplicity of variations in series of the most varied type. It is interesting to note that in natural retentiveness and speed of learning J. and R. represent opposite extremes.[2]

3. *Methods Employed by the Subjects in Learning the Series*

Between the 5th and 6th weeks of the regular work series were given for the sole purpose of studying the subjects' methods. During this week no other series were given. On the introspections of these series, and to a less extent on those given after the final tests of the regular series the following paragraphs are based. They refer to methods of learning only. Recall methods were a survival of some of the learning methods.

Fundamentally, the subjects did not differ in the methods they employed. Briefly, they all discriminated the terms of a series from each other, and partly at the same time, partly afterward, associated them with each other and with their spatial positions. The less the terms differed from one another the more necessary it was to differentiate them. In the two series which varied only in gray and violet, discrimination overshadowed association, and to the former the long learning times of those series were due. In series of pure colors and pure sizes discrimination was easier and briefer, while in the series in which form variation entered, voluntary discrimination was at a minimum. It was much more nearly instantaneous and involuntary. As one subject put it, 'discrimination was less necessary, because there was not much likelihood that the

[1] The meaning of these conflicts of method, etc., will become clear from the discussion of the next topic.

[2] See p. 63.

terms would be mistaken for one another.' It will be shown in the analysis of errors that with exceptions this remark was true. The subjects came to feel automatically on seeing a new series whether there would be in future much or little liability of mistaking one term for another, and increased or reduced the discrimination process accordingly. Except in the grays, violets, and pure sizes, *perceptual* discrimination in the simultaneous exposure was easy. It was the discrimination in *memory* which gave trouble. The other half of the learning process, the association, consisted in grouping the terms of a series. They might be grouped either because they were adjacent (contiguity), or because they were similar. Discrimination itself was likely to have impressed similarities, because it was similarity that provoked discrimination. The grounds of classification presented an ever-changing variety. A few of the most common will be mentioned in connection with the particular types of series, to which we pass after a word on the subject of language.

Language played small part in learning and retaining the series. Several subjects said that when the forms and colors were quite familiar they were apt to suggest names, and one said that sizes were thought of by the numbers 1 to 7, but that the numbers were not run together at all. This was the subject R. Not a single subject reconstructed the series from language cues, according to testimony taken at the close of the investigation.

Colors. The ends and the middle were conspicuous positions with all the subjects. They looked to see what was there, and if a striking color was in any one of them it was likely to be made the basis of a contiguity group or at least make the association of the term with its place easier. Other contiguity groups are illustrated by the introspections: 'Red and green are complementary and in 5th and 6th positions,' 'blue green is a familiar phrase and blue is on the left of green here.' Some of the similarity classifications which united non-contiguous terms were: 'The bright and the relatively colorless or dead ones,' 'the heavy and the light ones,' 'the violet pair,' the 'reddish ones,' 'colors on the border-line between the

seven spectral colors.' There was no hesitation in classing a blue green or a green blue, or even the lighter tint of blue as a blue in one series and a green in another according to the exigencies of the situation. *It is significant that the recognition of several colors, or sizes, or forms for that matter, as similar was both an aid and a risk,—the latter because it opened the way to subsequent confusion of the positions of the similar terms.* Two 'blue' colors or two 'low' forms were peculiarly liable to exchange of positions. The corrective was of course further discrimination. The number of groups in a color series was necessarily relatively large, because the series were constructed so as to give as much variety as was compatible with keeping inter-series interference at a minimum. This number varied from three to five.

Sizes. When in one series the 3d and 5th in size were next to each other, in another the 3d and 7th, and in another the 1st and 7th, and since six such series had been learned before the first two came up for final test, contiguity could not hope to prove a successful method of learning sizes, and was only rarely employed. Similarity was not used extensively if we exclude such contrasts as smallest and largest), because it led to the confusion mentioned in the case of similar colors. All of the subjects employed the same method. They grouped together a number of terms, often not contiguous, which formed, abstracting from the intermediaries, a continuous increase or decrease in size. A variation of the same method consisted in remembering the length, direction and position of the lines running through the tops of the groups. These lines were called 'sky-lines.' Some of these 'systems' or schemes were simple and natural, others complicated and natural, and quite a number both complicated and forced. By forced is meant not true without exceptions so numerous that the value of the scheme must have been slight. Several illustrations of the method may be given.

Sizes B. The correct order was 3416275.[1] The subject's system was an ascending 'sky-line' from 1st to 6th places, the

[1] The numbers denote the relative size of the terms, 1 representing the smallest.

smallest and next smallest forming a second ascending series interpolated in the first at the 3d and 5th positions. The last term stood apart.

Sizes A. The correct order was 5416372. The subject's system consisted of three 'sky-lines:' 541, 167 and 132.

One additional instance is given to illustrate the fact that subjects are not likely to hit upon the same scheme, unless it is very obvious.

A series of circles varying in size and shade or tint of red and arranged in the order 3261547 was given. One subject observed that the smallest was in the middle and the largest on the right end, that there were two pairs which decreased in size to the right (32 and 54), that 4 was nearest in shade to 7, and that the next largest was on the left of the middle. The second subject agreed with the first, as to the smallest and largest, but his further grouping was 321 and 654, in which two groups the direction and rate of decrease was the same, or was taken to be. The third subject made a rightwardly ascending group out of 147, a rightwardly descending group of 32, while 6 was discriminated from, and thereby associated with, 4 which it resembled in color. The fourth subject thought this series was easy for sizes, an opinion which the other subjects did not share. For her the middle one was the smallest, while each wing consisted, in order from left to right, of a medium, a small and a big one, with the larger three on the right. 2 was discriminated from possible rivals by its color, and 6 was the one nearest 7 in color.

It becomes evident that the schemes varied greatly in effectiveness. In the third illustration the one used by the last subject was extremely good, while that used by the third subject was poor. This fluctuation in the simplicity and naturalness of the systems explains the large variations in the retention of certain series of pure sizes and colored sizes as compared with the remaining series of the same types with the same person. For example, the unusually larger retention of Sizes I with certain persons was due to the discovery of the grouping 45, 12, 67, 3.

In the colored sizes the variation in color made the size

stand out but it also tended to check and break up the size schemes. The result was a mixture of the two methods, the superiority of which to either system alone the subjects were not agreed upon, according to their testimony quoted in the verbal summary of the last table.

Forms. Here again the subjects agreed in their methods, and it was substantially the same wherever form entered as a variation. If the color and size varied also, these were always subordinate means of recall. The form was the thing, and the detailed analysis of errors given in the Appendix shows conclusively that to the subject it was the same thing whether it was large or small, black or orange. Nevertheless, color and size variations were by no means ignored. They entered as secondary means of fixation, especially wherever a form was similar to another in the same series or a past series. Here the subjects differed some according to their own testimony already given.

It is surprising that only one subject in the six, R., habitually looked for resemblances to natural objects in the forms. There had been no instruction on this point.

Compared to the methods employed in the series of pure sizes and pure colors the form method was much more similar to the color method, but less strenuous. Voluntary inter-term discrimination was at a minimum because it was unnecessary. The discrimination was involuntary, immediate (the subject usually did not hunt for it) and sensorial rather than logical. Here alone was contiguity grouping a leading and effective method. The middle was frequently, though not always, fixated and one or both wings might then form units consisting for instance of a tall figure balanced by low ones on either side of it, as in Forms B, and III. The subjects repeatedly said that in form-varying series more than elsewhere they decided doubtful cases by the appearance of the series as a whole. Not that they had an image of the appearance of the series. Rather certain arrangements tentatively made did not look right. In this feeling they were more often right than wrong. Æsthetic considerations were prominent in series varying in form or color, but discord was as effective a vivifier as harmony.

4. Analysis of Errors.

For a detailed and probably more enlightening account of all the errors made by two subjects, N. and R., pages 80–7 should be consulted. A general summary of the errors of all the subjects will be sufficient here. Two types of errors are distinguishable: confusion and simple fading out. By confusion is meant all cases where the subject's arrangement has wrongly followed an arrangement in some other series or in another part of the present series, because of some similarity in color, size, form, or what not. The confusion need not be mental. Quite as often it is purely physiological, as will be noticed below. We shall class all errors not due to confusion as due to fading. An extreme case of fading is the following: A young man who had recently spent five years in the tropics was conscious that his mental processes had become sluggish, and his memory less impressionable. On the second morning of work in our experiment, although only one series of a kind had been learned the day before, and only three in all, he said, when the duplicates of some of the series were laid before him, that if he had been shown that series the day before, he was not aware of it! Our classification is the result, however, of the detailed analysis of errors. The two types are not meant to be mutually exclusive, but only to define predominant characteristics. It is true that confusion is apt to occur only after a certain amount of fading has taken place.

In the series of sizes, colors and colored sizes the type of error which we have called confusion is overwhelmingly the preponderant type. In the earlier series of colors the subject associates certain colors with certain positions. In later color-varying series he has to associate with the same positions colors which in memory at least he does not distinguish from the earlier ones. Interference arises, which is more often not noticeable at the time of learning, if the learnings occur on different days, but which becomes marked in recall after twenty-four hours, and still more marked after two weeks. With the accumulation of series in which the color varies, recollection in the final

test becomes worse. The interference may or may not be mental. It frequently is so, but on the other hand if the subject is following an arrangement in another similar group (similar in almost any respect), he is apt to feel quite sure that he is correct. After a number of color-varying series the subject is apt to say when trying to recall their order in a final test that the colors look about as well in one place as in another. By this he means that colors which he has classed as yellow, for example, have stood in a good many different positions, and he is uncertain which one this yellowish term belongs in. Exchange of colors in the same series is not as common as confusion of different series, because in construction the colors were intentionally varied; still, it does occur, for example when two or more colors have been grouped on account of a common property not reckoned with by the operator, as dullness, brightness, complementariness, togetherness in the subject's past experience. We have had occasion before to speak of intellectual classifications as a cause of confusion of position when not followed by further discrimination.

In series of sizes and colored sizes confusion of terms within the same series is much more frequent than in colors. This means the sizes are less discriminable perceptually. Confusion of one series with another may occur within the same half hour (for example, pure sizes with colored sizes), and is more marked with longer intervals. On the second and third day of learning the subject may be aware of it and correct it partly or wholly. Or he may be unconscious of it. The different types of situations are the same as described above for colors. It has frequently happened, however, that a size-varying series has been arranged in a final test in the order of some other series with entire correctness, and still the subject was not aware of the mistake in identity! This has never happened with colors or with form-varying series, and is an evidence of the high degree of unity of the size-varying series, especially pure sizes. In this respect they are the equal of form-varying series. This is due to the 'sky-line' and mass-group systems used in such series, and described above in connection with the methods of learning. *The absence of errors of the fading*

out type in sizes is striking. Almost all of the errors made during learning were exchanges of sizes nearest each other in area, or nearest but one. Proof of this in the form of a quantitative statement is given on pp. 61–62 in connection with some experiments similar to these, and it is also shown very conclusively in less convenient form in the detailed analysis of the errors of R. and N. in the present experiment, to be found on pp. 80–7.

In series in which form-variation enters confusion is relatively much less frequent than in colors, sizes and colored sizes, and fading out is more common, the total number of errors being also much less. *Exchange of adjacent terms, or inversion, is the most frequent error.* It is due to not noticing the individual terms closely enough (insufficient discrimination). The subject relies on his sensory, non-logical impression, at the point where the error later occurs. This is adequate for the test which follows immediately after learning, but by the next day many of these details have faded out. We agree with Ranschburg that this type of error is relatively unimportant for studying the effects of similarity, because it is not a similarity type of error. However, confusion is by no means absent from form-varying series. Confusion of terms within the same series seldom occurs. Inspection of the plates shows why. But the single re-using of an old form, or the occurrence of forms which generically are the same, for instance two vases, crosses, figures whose general contour is triangular, etc., produces interference and confusion, the more striking only because it can be identified with more certainty, on account of the individuality of forms. The poor average recall of Forms II, Col. Forms III, and C. F. d. S. IV, and the individually poor recalls of N. and R. in C. F. d. S. II are due to the re-using of old forms.[1]

[1] N. and R. took the places of F. and Mc.P. in the experiment and learned the series in a somewhat different order from the one followed by the four other subjects.

5. *Other Experiments with the Same Bases*

Association with Temporal Order and with Numbers. In the last set of experiments, limits to the benefit of increasing the complexity in the direction of dissimilarity were found for four subjects at the level of pure colors and pure forms. The combination of color and size, themselves equal in difficulty, was no better than either alone; nor were the additions of color and size variations, in themselves poorer than forms, when added to forms, an aid. With two other subjects, however, the combinations were better than the variations singly. With them the limits lie in some further increase in complexity. We might have experimented with these two subjects further, adding still more variations to the same bases, or using more variable bases than colors and forms. Inviting as this was, we preferred to test the generality of the conclusion that a limit is to be expected with any subject on the level of pure colors and pure forms. This we did by repeating the experiments with new subjects, successive exposure and association of the colors and forms with other associates than spatial position.

The 24 series used in the foregoing section were given to one new subject with successive instead of simultaneous exposure, and he was required to associate each term with its temporal position in the series. The cardboard screens, which stood between the aperture through which the subject looked and the carriage by which the series were moved, were narrowed so as to expose only one term at a time. The series were entirely remounted for successive exposure on cardboard sheets, 11 inches high and 42 inches or more long. Instead of having all the terms rest on a base line, the middle points in the vertical diameters of the terms were placed on a line running the length of the sheet, midway between the lower and upper margins. When a form arranged in this way appeared top-heavy, it was lowered until the unpleasant effect disappeared. No fixation point was enforced. All of the conditions under which the previous series were given as to avoiding names, reviewing, use of duplicates to show the learner's progressive

mastery of the series, the requirement that the series be held perfectly for 24 hours before the learning was discontinued, were maintained here. The only changes were successive exposure, final test after 6 days instead of 13 and arrangement of the duplicates by the subject in their temporal instead of spatial order. The interval before the final test was shortened because successive exposure made the task more difficult. In the various tests the subject, as before, did not see the duplicates until the exposure was over. He then uncovered them and arranged them in their time sequence, one on top of the other, face down. Six series, one of each kind, were given each week. The subject worked on four successive days each week and a fifth if necessary to bring the series up to standard. Four new series were begun the first day and the remaining two on the second day. The rate of exposure was 50 strokes of the metronome per minute with an exposure on each alternate stroke. A term was thus exposed about 1.2 seconds. The subject regulated the number of repetitions of the series which he took, but less than a repetition of the whole series was never given. Thus the measure of the rapidity of learning was the number of repetitions and arrangements required to bring the series up to perfect retention after 24 hours. The following table gives the results. The figures on the left and right sides of the dashes give the number of repetitions and arrangements respectively required to learn the series; the figures under them give the amount recalled in the final test, 14 being a perfect score. In the lower half of the table the same recall is recalculated per repetition of learning, after reducing arrangements to their equivalents in number of repetitions. This equivalent was found by special experiments given for the purpose in the same manner as for the subjects of the preceding group of experiments.[1]

[1] See pp. 65–7.

TABLE 6. *Areas varied in Color, Size and Form associated with Time Position.*

Subject U.

COLORS.				SIZES.			
I.	II.	III.	IV.	I.	II.	III.	IV.
4–2 5.25	4–4 3.50	4–2 5.50	6–3 4.00	6–4 8.25	11–8 11.25	7–4 5.50	6–3 6.50
FORMS.				COLORED SIZES.			
3–4 8.75	4–4 5.25	3–2 11.50	2–2 10.00	6–4 5.00	4–4 5.00	6–4 6.50	4–3 4.00
COLORED FORMS.				C. F. d. s.			
6–4 11.50	3–4 14.00	2–2 6.50	3–4 14.00	3–2 11.50	2–2 9.00	3–2 7.00	4–3 8.75

Recall per Repetition.

Series.	COLORS.		SIZES.		FORMS.	
	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.
I.....	.715	.176	.650	.122	.903	.046
II.....	.327	.212	.472	.056	.491	.458
III.....	.749	.210	.402	.126	1.811	.862
IV.....	.363	.176	.589	.061	.589	.360
Av.....	.539	.194	.528	.091	.949	.432

Series.	COL. SIZES.		COL. FORMS.		C. F. d. S.	
	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.
I.....	.394	.060	.906	.347	1.812	.420
II.....	.468	.014	1.445	.539	1.683	.291
III.....	.512	.058	1.215	.038	1.103	.289
IV.....	.443	.011	1.445	.539	.970	.422
Av.....	.454	.034	1.253	.366	1.392	.356

A study of Table 6 shows that colors and sizes are remembered about equally well and, as usual, forms better than either. The combination of color and size is not as effective as either separately, but both colored forms and colored forms of different sizes are more effective than forms alone.

With the subject U. and two new subjects, W. and X., the same 24 series were next associated with the numbers 2 to 8. The same seven numbers were used in every series. They took the place of the seven spatial and seven temporal positions. Certain substitutions were also made in the series of pure forms, the result of which was that no form was used twice in all the form-varying series. This was effected by substituting Forms A and B for Forms III and IV, and the alternative figures called B in the plates for those of the same number, e. g., Fig. 6B was substituted for Fig. 6. Naturally the order of presenting the terms was frequently changed to prevent the entrance of position associations. The numbers were of a large, fairly heavy style, 16 mm. high. Nos. 3, 4, 6 and 7 were black and 2, 5 and 8 were red, to reduce the labor of learning,—an application of the advantage of variety to our own experiment. The series in the form in which they had been arranged for U. were used, and the numbers were pasted on the centers of the terms. Where a term had been lowered for æsthetic reasons the number was put on the horizontal axis of the series, equally distant from the right and left sides of the term. The altered orders used to prevent position association were: 1st rep., 1234567; 2nd rep., 2134567, 3d rep., 1235746, 4th rep. 1234576, then if more repetitions were necessary, the same order over again. In the tests the subject took a set of duplicate numbers mounted on circular microscope slide covers and placed them on his duplicate set of terms. All of the other conditions were the same as for the subject U., as described above. With X. the interval between the completion of learning and the final test was reduced to 3 days, because a greater interval was too long to produce sufficient recall. U. was used again in this experiment, mainly because his time was at our disposal. This was a divergence from the fundamental assumption of our problem,

namely that the combination of variations must not already have formed a unity in the subject's past experience. While he had not associated numbers with the series, the combinations of color, form and size were not wholly unfamiliar to him. Nevertheless, his results present no important difference from his previous work or from the results of the other subjects, and they are consequently included.

The results of this experiment are given in Table 7. The numbers on the left and right of the dashes give the number of repetitions and arrangements respectively required to bring the series up to standard, the numbers under them, the terms correctly associated after three days for X. and six days for U. and W. There were seven couplets in a series and a score

TABLE 7—*A. Areas varied in Color, Size and Form, associated with Numbers.*

	COLORS.				SIZES.			
	I.	II.	III.	IV.	I.	II.	III.	IV.
U	6–3 5	8–4 5	5–6 2	3–2 4	6–6 5	9–7 5	3–2 1	6–9 5
W	8–2 7	5–3 3	5–2 3	4–2 2	5–5 2	7–3 1	7–4 5	9–7 5
X	10–6 0	17–5 1	10–11 5	22–11 3	9–7 2	8–5 0	10–5 3	7–6 5
	FORMS.				COLORED SIZES.			
U	6–6 7	9–6 5	2–2 4	4–6 7	6–4 4	5–4 5	4–3 3	3–4 5
W	4–2 7	5–3 7	5–2 7	6–4 7	4–3 2	9–4 7	6–2 2	5–2 5
X	6–4 3	4–4 3	6–6 3	7–9 7	9–6 3	14–10 7	5–3 1	10–7 7
	COLORED FORMS.				C. F. d. s.			
U	3–2 7	4–4 5	3–2 7	2–3 5	6–4 7	4–4 7	4–5 5	2–2 6
W	6–4 7	6–4 5	5–2 4	5–4 7	4–2 3	5–4 7	4–2 7	4–2 7
X	5–5 4	3–2 3	3–3 7	7–4 5	6–6 3	3–4 5	3–4 7	3–2 3

TABLE 7.—*B. Areas varied in Color, Size and Form, associated with Numbers. Recall per Repetition.*

U.

	COLORS.		SIZES.		FORMS.		COL. SIZES.		COL. FORMS.		C. F. d. S.	
	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.
I.	.453	.062	.305	.060	.436	.050	.315	.083	1.103	.256	.552	.131
II.	.347	.044	.241	.006	.262	.224	.427	.029	.468	.379	.655	.028
III.	.132	.259	.156	.079	.747	.261	.332	.066	1.103	.256	.404	.279
IV.	.630	.239	.237	.002	.498	.012	.516	.118	.712	.135	1.121	.438
Av.	.391	.151	.235	.037	.486	.137	.398	.074	.847	.257	.683	.219

W.

I.	.875	.231	.400	.053	1.750	.321	.500	.153	1.167	.117	.750	.663
II.	.600	.044	.143	.310	1.400	.029	.777	.134	.833	.217	1.400	.013
III.	.600	.044	.714	.261	1.400	.029	.333	.320	.800	.250	1.750	.337
IV.	.500	.144	.555	.102	1.167	.262	1.000	.347	1.400	.350	1.750	.337
Av.	.644	.116	.453	.182	1.429	.160	.653	.277	1.050	.234	1.413	.338

X.

I.	.000	.055	.073	.033	.182	.006	.121	.049	.221	.158	.138	.210
II.	.033	.022	.000	.106	.207	.019	.232	.062	.365	.014	.371	.023
III.	.128	.073	.129*	.023	.138	.050	.078	.092	.645	.266	.519	.171
IV.	.059	.004	.220*	.114	.226	.038	.247	.077	.286	.093	.364	.016
Av.	.055	.039	.106	.069	.188	.028	.170	.070	.379	.133	.348	.105

* *Memorized order of numbers only.*

Summary of Part B.

	COLORS.		SIZES.		FORMS.		COL. SIZES.		COL. FORMS.		C. F. d. S.	
	Rec.	M .V.	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.	Rec.	M. V.
U.....	.391	.151	.235	.037	.486	.137	.398	.074	.847	.321	.683	.219
W.....	.644	.116	.453	.182	1.429	.101	.653	.211	1.050	.234	1.413	.338
X.....	.055	.039	.106	.069	.188	.028	.170	.040	.379	.133	.348	.105
Av....	.363	.102	.265	.096	.701	.089	.407	.108	.759	.229	.815	.221

of 1 was allowed for each correct association, with no partial credits. Part B of the same table gives the same recall per repetition, after calculating in the equivalents of the arrangements in terms of learning time according to the method described on pp. 65–7. A numerical summary follows the table and a verbal summary is given last.

Summary. Two of the subjects do considerably better with colors than with sizes, while the third, X., does not recall enough of either for comparison. For, as indicated in a footnote to Table 7, part B, he learned only the numbers in Sizes III and IV. During learning he mentally arranged the numbers in the order which they would have if the sizes had been exposed in the order from smallest to largest. These two series should therefore perhaps not be counted. *All three subjects do markedly better with forms than with sizes and colors. With U. and W. colored sizes are not better than color alone*, but size is substantially improved by the addition of color as would be expected. *But with X. colored sizes are much better than either color or size alone.* This is confirmed unqualifiedly by the introspections of the subject. For him pure colors or sizes were almost impossible after the first series of each, partly on account of their inherent difficulty, but more because of the interference of past associations. He made in memory few if any more color discriminations than the seven of the spectrum. *With U. colored forms and colored forms of different sizes are both more effective by considerable amounts than forms alone*,—an outcome which duplicated his records in the associations with temporal order. *The subject X. also profits by the increased complexity in both cases,—colored forms and colored forms of different sizes.* His recall is practically doubled in both cases, compared with pure forms. Here again the introspections confirmed the results. *W. on the contrary is not benefited by the additions to form.* Colored forms are even poorer. It is interesting to note that the three subjects differed very widely in natural retentiveness, that the one who remembered the least profited the most from increased variety, while the one who remembered the most did not profit by the additions in any case. U. occupies a middle place in

respect both to natural retentiveness and the use made of the additional variations. When asked at the close of the investigation whether the presence of color and color-size variations in the form-varying series was a help, as constrasted with pure forms, W. replied, "Only occasionally, when the forms are similar. As a rule I find sufficient variety in the form alone." And yet she did not take the forms to be copies of objects, except in the most obvious cases. They were simply colored areas. On the other hand X. looked for resemblances to objects constantly, and found them usually.

The distribution of the benefit of increased variety is the same as we have found before. The learning time is shortened and still the amount recalled after a week is greater. U. learns forms in an average of 5.25 reps. and 5 arrs., colored forms in 3 reps. and 2.75 arrs., and colored forms of different sizes in 4 reps. and 3.75 arrs. His average recalls are 5.75, 6 and 6.25 terms respectively. X. learns colors in an average of 14.75 reps. and 8.25 arrs., sizes in 8.50 and 5.75, colored sizes in 9.50 and 6.50. His average recalls are 2.25, 2.50 and 4.50, respectively. He learns forms in 5.75 reps. and 5.75 arrs., colored forms in 4.50 reps. and 3.50 arrs., colored forms of different sizes in 3.75 reps. and 4 arrs. His average recalls are 4, 4.75 and 4.50.

The results with these three subjects simply confirm and extend the conclusion reached with the six subjects. The change to successive exposure and a different association has shown no change in the conditions of learning nor in the results. After a brief treatment of two somewhat different topics in the next three sections, the results of the whole investigation will be brought together in the Conclusion.

6. *Analysis of Errors.*

In the 24 simultaneous series begun in V 2, it was found that in colors, sizes and colored sizes, confusion was quite decidedly the most frequent cause of error, and the detailed analysis of R.'s and N.'s errors would have shown that both of the possible kinds of interference, namely of terms within

the same series, and of different series with each other, were equally prominent. In the present experiments successive exposure made single schemes for the whole of a series practically impossible and the influence of past series became less. Memorizing became much more a couplet affair. The interference in the series of sizes and colored sizes particularly was almost wholly traceable to terms in the same series, as shown in the following summary, in which is included every error made in all the series in which there were three errors or less. It includes U.'s temporal-order series and U.'s and X.'s number association series.

Sizes and Colored Sizes.

SUBJECT	KIND OF ASSOCIATION.	NEAREST SIZES.	NEAREST SIZES BUT ONE.	ALL OTHERS.	TOTAL.
U.....	Temporal Order.....	8	4	2	14
U.....	Number Associations.....	21	4	0	25
X.....	Number Associations	17	5	4	26
Total.....		46	13	6	65

By nearest sizes is meant sizes nearest each other in area. These sizes were simply mistaken for each other. In the next summary the proof is less certain only because color similarity cannot be so objectively defined. Its definition is due to the opinion of the experimenter, aided by a Bradley Color Book. We included in our definition only colors obviously similar in perception, and therefore quite certainly took a narrower definition than the limits within which colors would seem similar in memory.

Colors.

SUBJECT	KIND OF ASSOCIATION.	SIMILAR COLORS.	NOT SIMILAR COLORS.	TOTAL.
U.....	Temporal Order	2	0	2
U.....	Number Associations	4	2	6
X.....	Number Associations	11	2	13
Total		17	4	21

In the form-varying series of the temporal order set of U., inversion of adjacent terms was the most common error, which result agrees with those of the corresponding spatial position associations. Of the 22 errors made in all the series in which 3 errors or less occurred, 15 were exchanges of adjacents, 4 were due to similarity in form and 3 to no assignable cause. Of the form-varying series of the number associations the only statement that can be made is that confusion due to similarity was less frequent than in the series of sizes and colors. Inversion of adjacents is here not a possible type of error on account of changes of the order in learning.

VI. INDIVIDUAL DIFFERENCES IN SPEED OF MEMORIZING AND IN RETENTIVENESS

If the differences in material be disregarded, the experiments described in V 2 give results from six subjects with the same 24 series. Since all of them were required to learn the series in the same way we may compare the subjects simply as learners. The three subjects used in the experiments with numbers cannot be compared with the first six only among themselves. The following table is compiled from the averages for the different persons given in Tables 4 and 7. Part A below gives on the left the average number of seconds which each of the first six subjects required to bring the series up to the point where he had held its arrangement perfectly for a day. On the right side are given the average amounts recalled, marked on a scale of 14. In part B similar averages are calculated for the three subjects in the experiment with numbers. These figures also are based on 24 series and the amount recalled is based on a scale of 7. The subjects are arranged in order of speed of learning and amounts recalled.

TABLE 8.

Part A.

SUBJECTS.	TIME.	ARRS.	SUBJECTS.	AMOUNT RECALLED.
R	:22	3.17	H	9.16
N	:26	3.42	N	8.31
G	:33.5	3.25	J	8.02
H	:38.8	2.88	R	7.64
L	:46.7	2.92	G	6.97
J	:60.2	2.92	L	6.92

Part B.

SUBJECTS.	REPS.	ARRS.	SUBJECTS.	AMOUNT RECALLED.
W	5.38	3.08	U	5.04
U	4.71	4.17	W	4.96
X	7.88	5.63	X	3.75

N. learns rapidly and retains well; R. learns rapidly and retains moderately. H. is just the converse: he learns moderately, being a tie for third place, and retains well. G. learns moderately but does not retain as well. J. gets some recompense for his extra effort, while L. learns slowly and retains with difficulty.

W. and U. learn rapidly and retain well, there being very little difference between them. W. is the more retentive for longer intervals. For a week—the interval of their test—there is no difference between them, but W. retained series for weeks after U. had forgotten them. X. learns slowly and has difficulty in retaining.

Temperamental differences also come out in the willingness to take a chance. This is shown by the number of arrangements. N. and G. were speculative. They frequently terminated the exposure of the series before they had learned them sufficiently. These were the subjects who had on occasion to take five days to learn the series instead of the usual three. L. and J. are cautious. When they end the exposure it is safe to say they have the series for that day, and quite probable that they will have it the next day without re-exposure.

VII. EXPERIMENTS TO DETERMINE THE VALUE OF ARRANGING[1]

After all of the foregoing experiments had been completed, 12 series were given to the subjects, G., H., J., L., N. and R. There were four series each of colors, sizes and forms. Two of each were learned in three successive days all six being begun on the same day. The other six were given the next week. In one of the two color series of the first week arranging was required as in all the foregoing experiments, in the other it was omitted till the final test. The same is true of the two series of sizes, and the two forms learned the first week. The times of exposure were the same for every correlative pair, the one with and the one without arranging. During the first week the series with arranging preceded their mates to allow the subject to determine the length of the learning periods. However, to prevent the series without arranging from being at a disadvantage from too short exposure, certain extra exposures were given by the operator on the third day. To be

[1] This question is very important wherever it is desired to study the learning process as well as the recall. For in order to ascertain the learner's progress towards complete temporary mastery of the material it is necessary to test him from time to time. This gives two different measures, learning time and testing time or number of tests. The attempt to reproduce a material nearly always aids in memorizing it. Ebbinghaus assumed that a test or attempt to repeat a series is equivalent to a presentation of it, but this is clearly unsatisfactory. Stephan Witasek has made an exhaustive study of the relative efficiency of readings and attempts at recital in bringing series of nonsense syllables up to perfect memorization, and in producing recall after an hour. (Ueber Lesen und Rezitieren in ihren Beziehungen zum Gedächtnis. Ztsch. f. Psych., 44: 161–85 and 246–82.) He found that for immediate recall 6 readings and 5 recitations enabled the persons to recite the series in one half the time required by 11 readings alone, and required only one thirteenth as many promptings. (The Ebbinghaus prompting method is the one referred to.) The superiority of the recitation in producing recall after an hour is not as marked as in immediate recall. Thus various mixtures of readings and recitations, the readings of course always preceding, compared with an equal number of readings alone, effected an average saving of about 11 per cent in time and 16 per cent in promptings in the final test. The foregoing disregards time consumed by the two methods. A recitation aided by promptings takes more time than a reading. However, the author shows that even on a time basis a combination of readings and recitations is more economical than readings alone. From any point of view recitations are far superior to readings in impressing value. The significance of this result for pedagogy, for determining the best methods of study, is worth noting.

more explicit, on the first day the subject wholly determined the time. He took as much as he thought would enable him to arrange the *first* series of each pair correctly the next day, and the operator allowed him the same time on the second series of each pair. On the second day the procedure was the same *if* he did *not* have them correctly in the preliminary test of that day. If he *did* have them correctly, he was given a 7-second exposure of both series of the pair. The procedure was repeated on the third and last day, for sizes and colors, but forms were dropped after the second day, because they would have been over-learned by continuance. The aim of these conditions was to bring the series approximately up to our previous standard, perfect retention for a day. However, since having arranged a series was equivalent to seeing it again, and since it was desirable for exactness to spread the learning time of both types of series over the same number of days, it was necessary to give a brief exposure of *both* series (the one with and the one without arranging) whenever one was seen. This was the purpose of the 7-second exposures. Hence our procedure was slightly different from the one used in the past. In the second week the operator wholly determined the length of the learning times, and made them the same as the series of the first week for that subject. The series without arranging now preceded its mate. Finally, there was a reversal within the pairs. The series in connection with which three of the subjects arranged were the ones with which the other three subjects did not arrange. The purpose of this reversal was to test the assumed equality in difficulty of the correlative series. The results substantiated the assumption in the main.

All the other conditions were the same as in the simultaneous series of V 2. The subject was required to associate the terms with their spatial positions. The series were displayed on cardboard sheets, 14×22 inches, the arrangement being in three vertical columns of two terms each, except the middle column, which had three. The usual expedients to minimize interference, in particular, individual series-shape and series-color, were used. The final test of the first six series occurred

in the midst of learning the second six in order to retain the normal interference factor, constantly operative in our past work.

The procedure with the three successive subjects U., W. and X. was similar. The consonants G, H, N, P, Q, W and Y were associated with 12 series, 4 each of colors, sizes and forms. Three of the letters were white, the rest black. The learning conditions were modeled after those described above, while the testing conditions were the same as in the regular work of these subjects.

For the six simultaneous subjects the value of an arrangement was determined by dividing the total number of seconds spent in learning the six series in which there was no arranging by the number of terms recalled in those series after a week, and then dividing the difference between the total recall in the six series with arranging and the six without, by the total number of arrangements used. The first operation gave the number of seconds of learning time that would produce one term in recall with this subject, while the second operation gave the number of arrangements, or the fraction of an arrangement, that would produce one term in recall. These two quantities were therefore equivalent. Precisely the same method was pursued in calculating the value of an arrangement for the successive subjects, except that the learning times were given in repetitions instead of minutes and seconds. The values thus obtained for the different subjects were as follows:

Value of an Arrangement.

SUBJECT.		SUBJECT.		SUBJECT.	
G.....	5 secs.	L.....	10 secs.	U.....	1.673 reps.
H.....	12.35 secs.	N.....	12.35 secs.	W.....	nothing
J.....	21.8 secs	R.....	10 secs.	X.....	2.617 reps.

For the two subjects who were dropped from the experiment after the series of grays and violets, McP. and F., 10 secs. was taken as the value.

VIII. CONCLUSION.

In summing up the results of the investigation, it is well to call attention to the fact that it is not primarily an inquiry into the effects of novelty on memory. Had this been the aim the same typographical variations would not have been used for eight consecutive weeks, nor the same variations in plane areas for over four months. The experiments rather contrast the effects of simplicity with dissimilar complexity, when a few types of each are used a long time.

Language, spoken and written, is full of symbols relatively simple and similar. The sameness of a page of print contrasted with the variety afforded to the eye by looking at natural objects is striking. The possibilities, however, of improving the memory for language, by introducing mechanical variations, as suggested to us by the experiments of Dr. Gordon, have proved to be decidedly limited. In the absence of variation in meaning, as is the case with nonsense syllables for example, the memory is permanently improved by the addition of a few variations, particularly position and size, but if the number of variations be increased considerably, say to three or four, distraction enters, there is no further improvement and there may be a loss. That such variations are of great aid in arresting the attention, when they have the feature of novelty, is a popular conviction which experiment would doubtless verify. If, however, the variation takes the form of experiencing fewer of one thing than of another, the memory for the few is certainly better than the memory for the many, as proved by the experiments of Prof. Calkins.

But language differs from nonsense syllables in having meaning, in itself a powerful variation, and the experimental results give no basis for the belief that the memory for language is permanently better, when the words vary in mechanical ways. Our own experiments were few in number, but convincing. When the attempt is made to vary the meaning, a difficulty in technique arises, which is by no means a small one, namely, the difficulty of keeping the simpler material simple and disconnected. Even single adjectives or two-place numbers sug-

gest acquired connotations so readily that the material rapidly becomes complex, and has the advantage over the material called complex that it is already made up of *units*. This was the case with our experiments with words and sentences, and numbers and biographical facts. However, the results at least show that when the learning time is fixed and sufficient for comprehending the meaning of both, short sentences can be as well remembered as single words. All three of our language experiments showed conclusively that a person will seek differentials among the things to be associated, but will give the preference to ones already connected in his experience, if they can be found.

We pass next to the experiments with plane areas. We found that forms were far more associable than colors and sizes, that is to say, the associations were much more quickly established between forms and something else than between colors or sizes and something else. In this result all nine subjects agree. We know of no other experiments on this subject except those of Bigham.[1] He found that colors were slightly more associable than forms in immediate recall, but after 2 hours and 24 hours the result was the reverse by larger differences than before. The res onse times in immediate recall of forms were also longer than in the case of colors. His method was similar to ours in the use of duplicate series for testing, but differed in the very important respect that the same ten forms and ten colors were used over again in every series. The test was association with position as in our experiment. The re-use of the same forms would under these circumstances produce interference, the greater for forms because of their more ready associability. The better recall of forms after two and after twenty-four hours, that is the fact of reversal, cannot be understood without knowing how many series of a kind were given.

The relative associability of sizes and colors differs in our results with different subjects, with the balance in favor of colors. Four persons remember colors better; two, sizes; and

[1] Bigham, John: Memory. Psych. Rev., 1894, I, 453.

two show no marked difference. The ninth subject is disregarded because of low recall. However, if the slighter differences shown by two persons classed as equal be counted, six remember colors better than sizes, while two are the opposite, and by very large amounts in both cases.

The very great superiority of forms over colors and sizes is certainly due to the far greater variety within a limited space which the realm of forms offers. Had all the form-varying series, instead of one-half, consisted solely of forms used only once, the superiority of forms would have been still greater by a considerable amount. Yet as many forms as that could easily have been found without making the similarity great. The simple fact is that there is a large number of easily discriminable forms, while there are only a very few easily discriminable colors and sizes, so far as the memory for long intervals is concerned. On the other hand the experiment does not do justice to the possibility of color. It would be interesting to know what would be the result of combining several colors in each term. The striking color effects of practical life are oftener color contrasts than single colors. While only experimentation can decide the question, our own results lead us to expect only slight improvements for color from this source.

While our earlier experiments were relevant to the memory for language, the later ones with plane areas are like the memory for objects, and here our results were much more positive and extended. We may disregard the differences between the associations with position and those with numbers, and treat all nine subjects together. The questions raised in the original statement of our problem may be answered as follows. On the low level of variety represented by shades of gray and shades and tints of one color, the advantage of additional variations is great and is manifested by all six subjects tried. By a mental economy the additions, here more easily discriminated than the grays and violets, become the more prominent, although a *bona fide* association is made between them by the time the learning process is complete. In most cases the person could tell which gray, or shade or tint of violet, went with a form or size, if given both variations to put together. This process of

remembering a less discriminable thing by a more discriminable associate is easily identified in life. Students distinguish their notebooks by the fasteners, marks of rough usage or even bits of color. Books are distinguished by their variation in color, because the shape is so much less discriminable. In education arithmetical rules are clothed in striking examples.

With the passage to the higher levels represented by different colors and different forms, when the variations added are less discriminable than the bases, five of the nine subjects no longer profit by the increase in complexity. The two other persons in the simultaneous position associations and two in the number associations with areas still profit. No limit was found for them. When, however, the variation added is more discriminable than the base, all of the subjects again profit by the addition. This is the case when in our type of series called Colored Forms a form variation is added to color. The advantage is almost as marked as on the lower level.

The question why the increases in complexity cease to be an advantage is next in order. The ability to profit by these increases is not a function of speed of learning, as would naturally be expected. Quickness in learning here represents good powers of discrimination and facile associative processes. The figures given in Table 8 show that of the four persons who profited longest by the increases in complexity, R. and J., and U. and X., two rank first and two last in rapidity of learning the series. The ranking is the same if only pure colors, sizes and forms are averaged. This restriction can be demanded with some justice, because if those who have trouble in discriminating the terms are the ones who profit longest by the added variations, their slower discrimination would show itself most before the variations were added.

On the other hand the five to whom the complex material was not the better are in agreement as to the presence of distraction in the complex series. While distraction is therefore the most probable cause at the present time, special experiments on the span of attention are necessary to decide the matter.

It is now possible to offer an explanation for some of the differences in the memory for different materials, and the same

materials learned in different ways, which were spoken of in the beginning. Objects, actions and pictures are better remembered than words, because they are more extensive and varied stimulations. Both get a certain amount of variation from the ideational suggestions called forth, by the connotations, in other words. It is probable that the ideational supplementation is somewhat richer for words than for objects, actions and pictures. But with most persons imagery is feeble compared with sensory stimulations, and we are inclined to believe that the advantage which words may enjoy in this respect is relatively slight. On the other hand in the extensiveness and dissimilarity of sensory stimulations a series of words cannot compare with a series of objects or pictures. This is ludicrously brought out when one attempts to handle type. We rest our eyes from print by looking at our surroundings. Contrast the extent and variety of stimulation obtained from looking at a house, a lawn, a lamp, a knife, a piano-player and a moving train of cars with the smallness and similarity of the stimulations obtained by looking at their printed words just given, or even printed and read aloud. Corresponding to the more extensive and varied original brain excitations of things are the more easily aroused and numerous mental cues in recall, and the greater likelihood of freedom from the interference due to similarity. If the brain excitations obtained from seeing and hearing the series of things mentioned above be denoted by the letters ABCD, DEFG, GHIJ, etc., those obtained from looking at their printed names and speaking them should be represented by the letters mnop, nopq, opqr, etc., even after the differences due to suggested imagery are included.

The explanation is the same for the fact that words presented to several senses are better remembered than those presented to one only. Whitehead has shown that when things are learned visually, there is a filtration, so to speak, through from our visual to our auditory experience taking place at the time of the visual learning, so that if a week later the same thing be learned auditorily, it takes but little more time than to relearn it visually, and of course much less time than to learn a new series auditorily.[1]

[1] Whitehead, L. G.: Psych. Rev., 1896, III, p. 258.

The same thing is true if the first learning is auditory and the second visual. Here as in our own experiments the connecting process goes on during learning, but in this case the connection is with images instead of other perceptions. The same process takes place in learning through several sense organs at once. If we not only see but pronounce, we get a more varied stimulation than if we merely see the words, and if we read them aloud the stimulations are still more varied compared with the visual alone, and the liability to confusion in recall is correspondingly less, just on account of this growing variation. Doubtless the well-known summation effects of a number of weak stimuli are also responsible for the difference. We seem to get the *meaning* more completely when we read a page aloud than when we read it to ourselves. This indicates that the visual, auditory and enunciatory stimulations combined are more effective than one or two alone in arousing associations of an ideational type. Furthermore, it is not to be forgotten that we are dealing here, in the case of language at least, with complexes that are already apperceptive units, owing to early schooling. The case is somewhat different from that of our own experiment, where the combinations were constantly new.

One of the original and less common features of this investigation is the length of the interval before the memory is tested. There are few extended investigations of the memory for materials after intervals as long as one and two weeks.

Finally, to the technique of memory work we offer a contribution. The method of measuring the memory for different materials by the amount of time or repetitions required to bring them up to the same level of efficiency meets with the difficulty of evaluating the tests taken to determine progressive efficiency. We propose a solution of this difficulty, namely, a separate determination for each person, of the average worth of a test in terms of learning time or repetitions, the two measurements to be rendered equivalent through what each will produce in recall.

IX APPENDIX.

1. *Plates.*

The following plates give the shapes and *relative* sizes of the form-varying series. The actual dimensions and the colors employed are given in the 'Description of Series' on the pages immediately succeeding.

With three subjects *U*, *W*, and *X*, certain forms, here called 'Substituted Forms,' replaced some of those in the regular series in order to eliminate repetition. They are numbered to correspond with the figures which they replaced, and the distinctive letter B is added. The first three forms, 1B, 4B, and 5B belong to Forms I; the fourth, 7B, belongs to Forms II; and the last two in the row, 1B and 6B, belong to Forms B. In the next row 1B, 2B, and 7B belong to C. F. d. S. III, and the remaining five belong to C. F. d. S. IV.

2. *Description of Series used in V 2 and 5.*

Colors. Each term contained 50 sq. cm.

Series I. Eight-point stars. Yellow orange t. 2, green, cool gray no. 1 blue sh. 2, A-yellow medium, green yellow t. 2, red orange sh. 1.

Series II. Squares. Orange red t. 2, yellow orange sh. 2, A-blue green dark, yellow, red, green t. 1, A-red light.

Series III. Oblongs. Orange yellow t. 1, red violet sh. 2, orange red t. 1, blue green sh. 1 green yellow t. 1, A-green yellow dark, A-green light.

Series IV. Round-cornered squares. Black, violet red t. 2, orange red sh. 2, cool gray no. 2, green sh. 2, A-yellow orange medium, green blue sh. 1.

Sizes. Series 1. Red oblongs, height twice the width. Irregular ratio of terms as follows: 1 : 2 = 4, 2 : 3 = 3.06, 3 : 4 = 1.24, 4 : 5 = 1.5, 5 : 6 = 1.4, 6 : 7 = 1.5.

Series II. Equilateral triangles. A-yellow orange dark. Geom. ratio, 2.77, beginning with an area of .5 sq. cm. for the smallest.

Series III. Circles. Blue violet sh. 2. Geom. ratio, 2.77. Smallest term, .5 sq. cm.

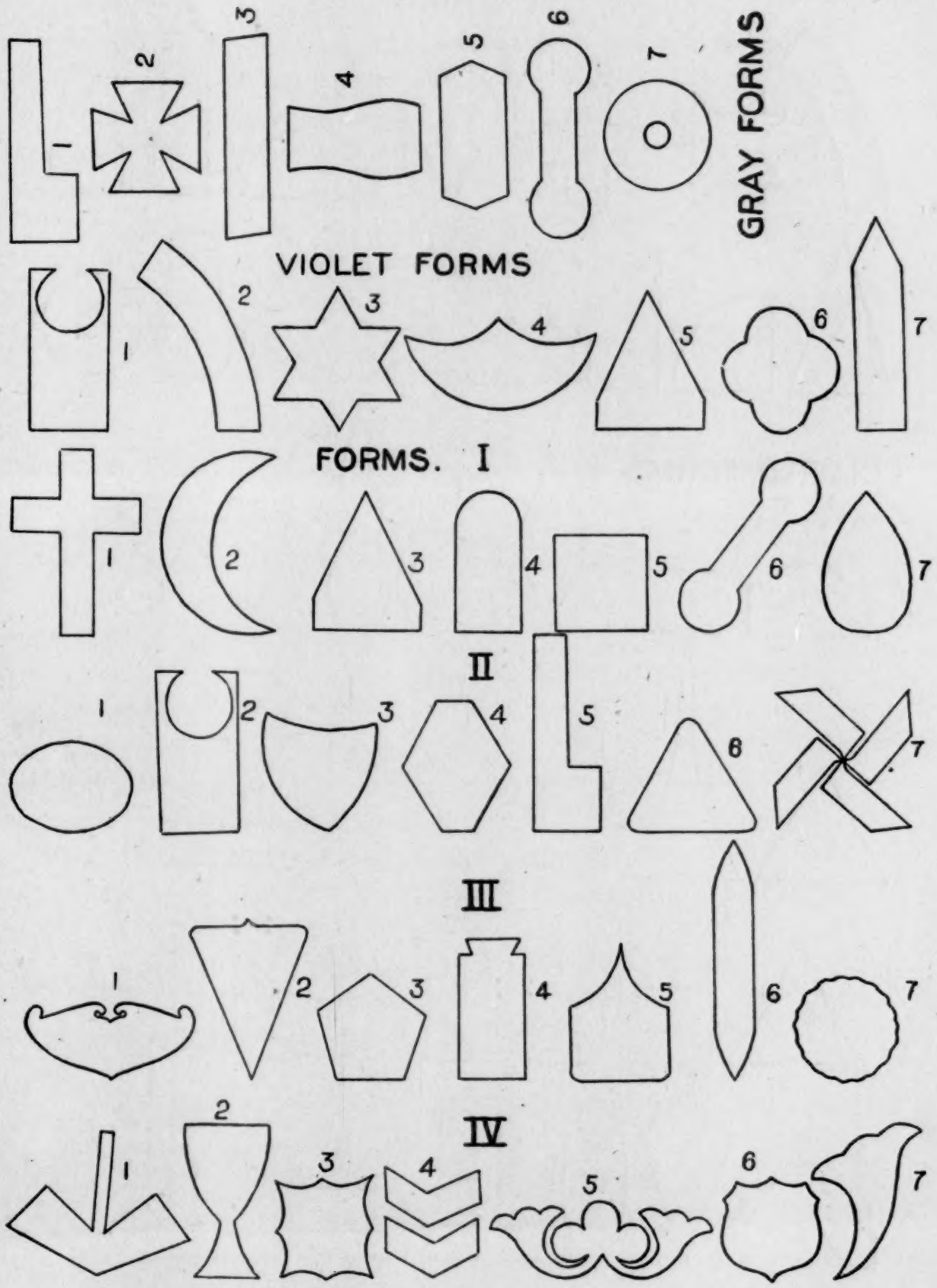
Series IV. Truncated cones, sides inclined one-tenth the width of the base on each side. Yellow orange, and irregular ratio of terms as follows: 1 : 2 = 3.9, 2: 3 = 4.1, 3 : 4 = 2.98, 4 : 5 = 1.69, 5 : 6 = 2.1, 6 : 7 = 1.9.

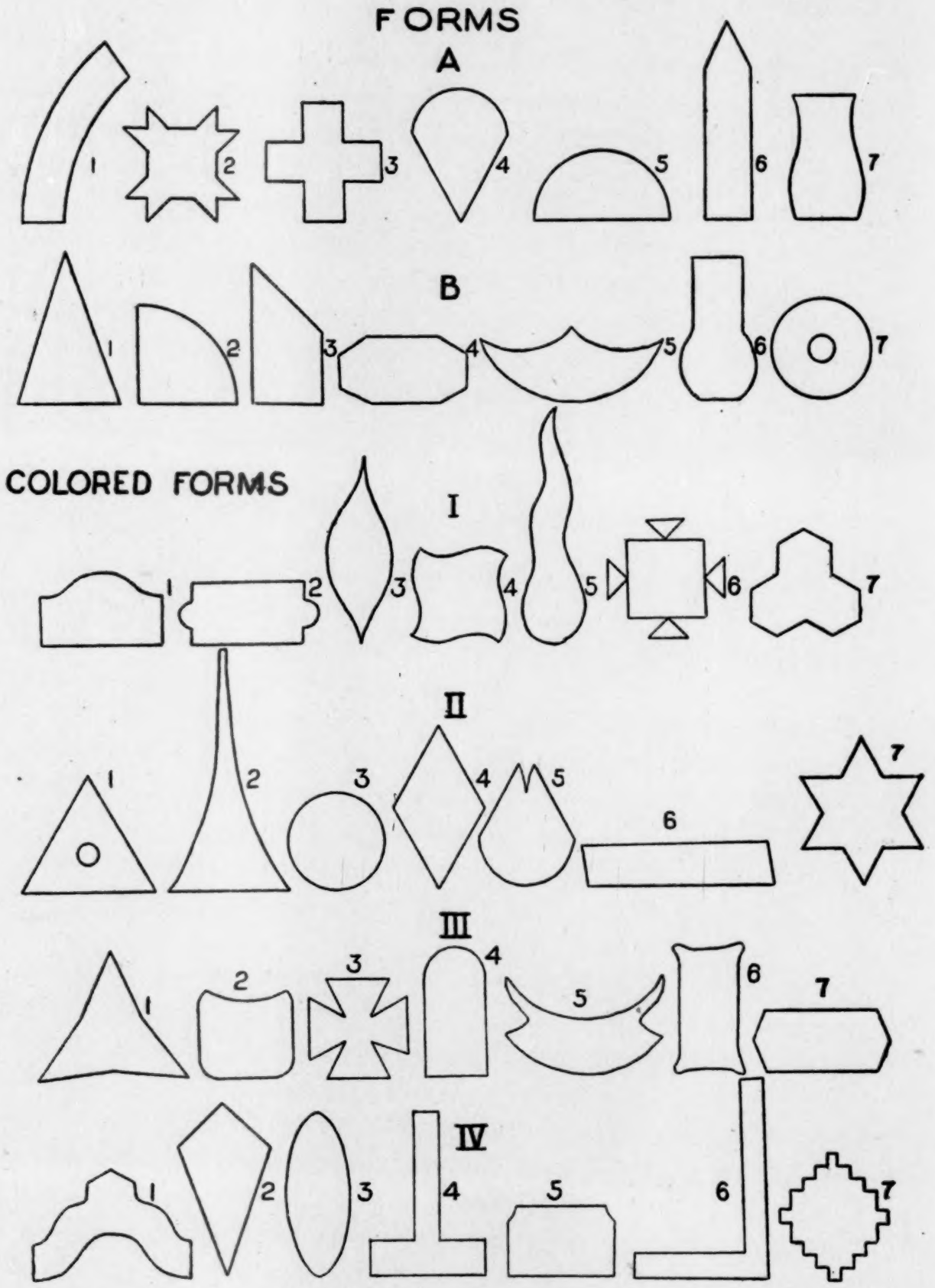
The order in which the sizes were placed in any series was determined by chance as in the gray and violet sets, excluding the cases there excluded. The arrangements employed in the above series were the following, reading the series from left to right. The figures give the areas in sq. cm.

Series I. 40.5 60.5 2 8 84.5 128 24.5.

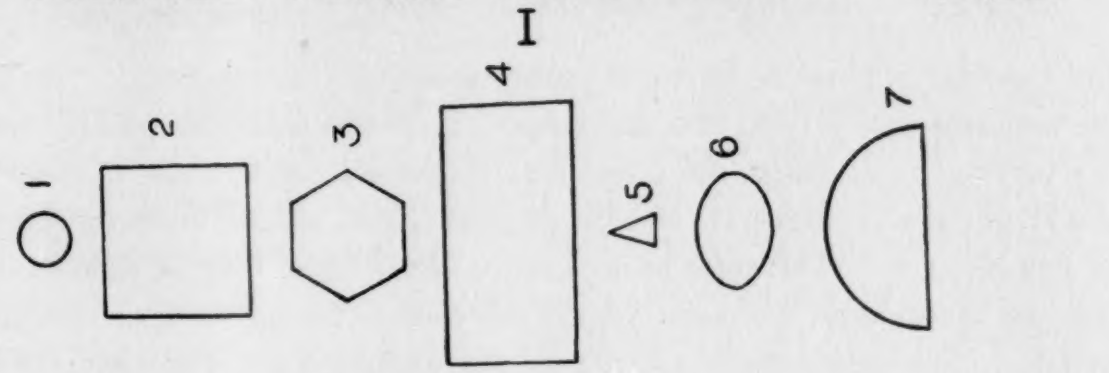
Series II. (1 is the smallest) 1625347.

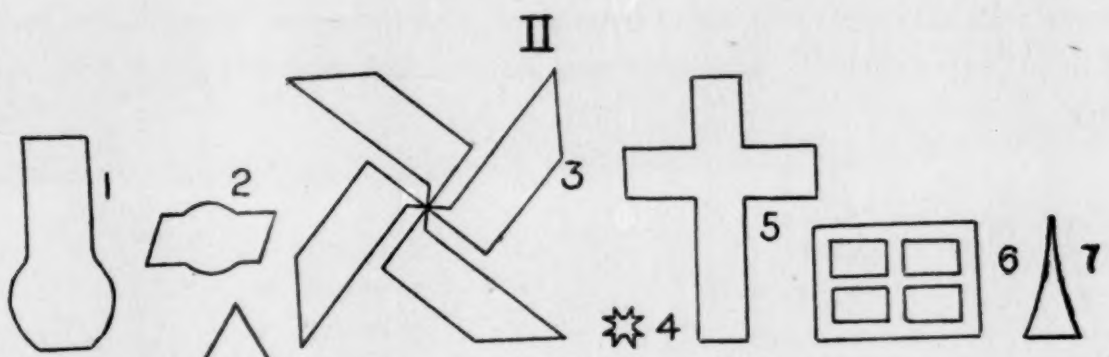
Series III. 2451376.

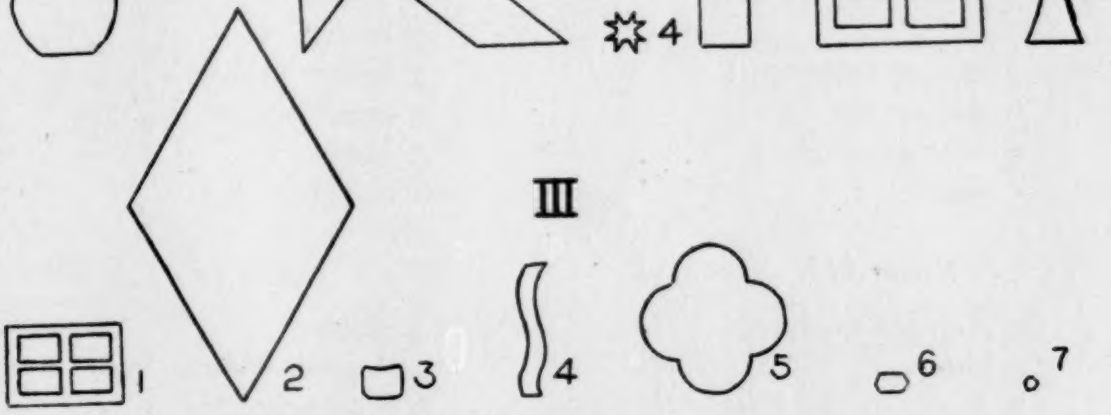

GRAY FORMS
VIOLET FORMS
FORMS. I
II
III
IV

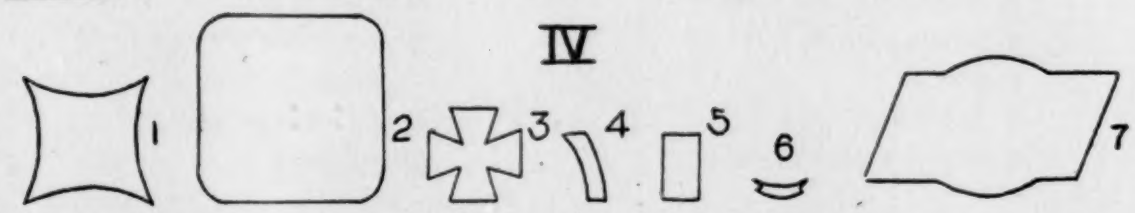

FORMS
A
1
2
3
4
5
6
7
B
1
2
3
4
5
6
7
COLORED FORMS
I
1
2
3
4
5
6
7
II
1
2
3
4
5
6
7
III
1
2
3
4
5
6
7
IV
1
2
3
4
5
6
7

COLORED FORMS OF DIFFERENT SIZES.

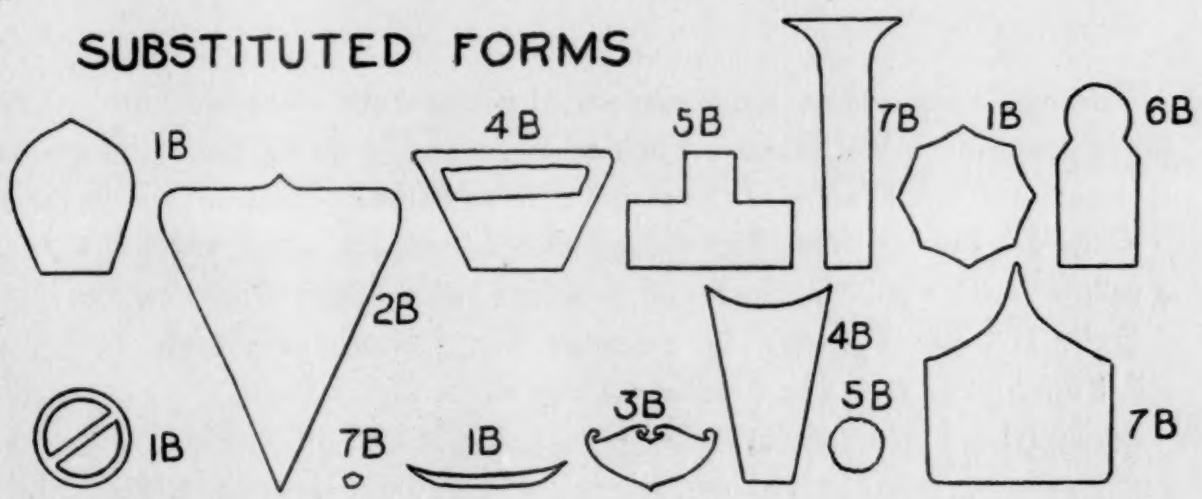








SUBSTITUTED FORMS



Series IV. 1.95 .50 40.6 162.2 24 8.05 84.
It will be noted that the aggregate area of each series was 350 sq. cm.

Colored Sizes. These series are the simplest advance in complexity. As the name indicates they vary in area and color. To render them comparable with series varying in size only, the term-areas of Series I repeat those of Sizes I, Series II, of Sizes IV, Series III and IV, of Sizes II and III. The series-shapes were however new. The order of occurrence of the terms may be represented as follows, the topmost one being on the left end. The figures again indicate the sizes, 1 representing the smallest, 2 the next smallest, etc. The combination of color with size was determined by chance after the seven colors for the series had once been selected. However very small terms were not given very light colors.

Series I.

2 yellow green
3 yellow orange dark
1 red sh. 2
7 orange yellow t. 1
6 red orange
4 blue green sh. 2
5 violet t. 1.

Series II.

2 blue
1 orange red
5 orange sh. 1
7 yellow orange t. 1
4 green yellow
3 blue t. 2
6 red violet t. 1.

Series III.

3 A-green medium
4 blue t. 1
7 A-orange red dark
5 green yellow t. 2
1 black
6 A-orange light
2 A-red violet dark

Series IV.

3 violet
1 A-green yellow dark
6 blue green sh. 1
2 A-yellow orange light
5 green blue t. 2
4 red orange sh. 2
7 yellow t. 2

Forms. (See plates.)

Colored Forms. These series also varied in two ways, color and form. The forms are given in the plates. Each term contained 50 sq. cm. The colors in order from left to right in the series were as follows:

Series I. Fig. 1 yellow, Fig. 2 A-green medium, Fig. 3 red violet t. 1, Fig. 4 yellow green, Fig. 5 black, Fig. 6 A-orange red medium, Fig. 7 orange t. 2.

Series II. Fig. 1 green, Fig. 2 orange, Fig. 3 orange yellow sh. 1, Fig. 4 red, Fig. 5 green t. 2, Fig. 6 yellow orange sh. 2, Fig. 7 violet.

Series III. Fig. 1 A-yellow orange dark, Fig. 2 blue sh. 2, Fig. 3 red t. 1, Fig. 4 yellow green, Fig. 5 orange yellow t. 1, Fig. 6 red violet sh. 1, Fig. 7 yellow green sh. 2.

Series IV. Fig. 1 warm gray no. 1, Fig. 2 orange yellow t. 2, Fig. 3 green yellow t. 1, Fig. 4 blue t. 1, Fig. 5 A-orange red, Fig. 6 violet red, Fig. 7 A-yellow orange medium.

Colored Forms of Different Sizes. These series varied in three ways and represented the maximum number of variations which were combined in a single series. The variations were in color, size and form. The forms are given in the plates, the sizes and colors, here. The ratios existing between each two successive terms in series I and II were the same as in Sizes I, and the actual areas were also the same as there. In series III and IV the ratios were
1 : 2 = 4, 2 : 3 = 2.25, 3 : 4 = 2, 4 : 5 = 2.17, 5 : 6 = 2.6, 6 : 7 = 3.25.
1 : 2 = 2.5, 2 : 3 = 2.5, 3 : 4 = 2, 4 : 5 = 2.5, 5 : 6 = 2.17, 6 : 7 = 1.35.

Series I.

Fig. 1	8.	sq. cm	A-yellow orange dark
" 2	84.5	"	violet red
" 3	40.5	"	A-yellow light
" 4	128.	"	yellow
" 5	2.	"	A-blue dark
" 6	24.5	"	yellow green sh. 2
" 7	60.5	"	blue

Series II.

Fig. 1	60.5	sq. cm	green t. 1
" 2	24.5	"	orange yellow sh. 1
" 3	128.	"	warm gray no. 2
" 4	2.	"	orange red
" 5	84.5	"	green blue sh. 1
" 6	40.5	"	orange
" 7	8.	"	A-red light

Series III.

Fig. 1	19.2	sq. cm	black
" 2	162.	"	violet
" 3	4.5	"	orange yellow sh. 1
" 4	9.	"	red violet t. 2
" 5	50.	"	yellow green sh. 2
" 6	2.	"	red t. 2
" 7	.5	"	blue t. 1

Series IV.

Fig. 1	43.75	sq. cm	blue violet
" 2	128.	"	green blue sh. 1
" 3	17.5	"	violet red
" 4	3.5	"	warm gray no. 2
" 5	8.75	"	green yellow sh. 2
" 6	1.4	"	red sh. 2
" 7	95.	"	A-yellow light

Each of the first two series aggregates 348 sq. cm., the third 247 and the fourth 298 sq. cm.

Extra Series. Colors A. Blue sh. 2, yellow orange sh. 2, violet, orange, green, A-violet blue light, red. Oblongs, height twice the width.

Colors B. A-yellow light, red violet t. 2, red t. 1, yellow, warm gray no. 2, blue green, yellow green t. 1. Same series-shape as in the preceding one.

Sizes A. Isosceles triangles, height twice the base. Blue t. 2, geom. ratio of 2.5 beginning with an area of .5 sq. cm. for the smallest term. Total area of series, 204 sq. cm. Order: 5416372.

Sizes B. Truncated Cones, A-yellow dark in color. The ratios were 1 : 2 = 4.5, 2 : 3 = 2.78, 3 : 4 = 2.6, 4 : 5 = 2.03, 5 : 6 = 1.3, 6 : 7 = 1.92. The actual areas in order from left to right were, in sq. cm.: 25 64 2 169 9 324 130. The total area was 723 sq. cm.

Sizes C. Quadrilaterals formed by superposing upon a square a right triangle of the same dimensions with hypotenuse to the left. Green sh. 2 in color. The ratios were, 4, 4, 3, 3.5, 1.93, 1.58. The actual areas in their order were in sq. cm.: 2 162 24 84 256 .5 8. The total area was 536.5 sq. cm.

In the next two series the areas of Sizes I were used.

Colored Sizes A.	*Colored Sizes B.*
4 blue green	5 orange red sh. 1
2 red orange t. 2	2 green sh. 2
7 warm gray no. 1	4 orange yellow t. 1
5 green t. 2	3 red t. 2
1 red orange	7 cool gray no. 1
3 blue t. 1	1 A-yellow orange dark
6 A-green yellow medium	6 blue

Forms A and B. These are sufficiently described in the plates. The results obtained from them were not used in the tables, because the forms in them had been used once before, and there was already a sufficiency of such series.

3. *Analysis of Errors in V 2.*

In the pages immediately following the errors of Tables 4 and 5 will be analyzed. The results of two subjects will be treated in detail including every series, every error in the final test and some of the errors made in learning. Some of the explanations are conjectural, and of questionable worth; many others are beyond question the true causes of the errors. The account is to a very large extent a story of interference due to similarity. It will be recalled that introspections were not allowed before the final test, so that when they

were given, most of them were not of value. The conclusions given below are therefore mainly the result of a study of the arrangements of duplicate series handed in by the subject. Where introspections were used it is made evident in the text. The extra series denoted by the letters A, B, etc., are included. It is essential to remember that in the interval of 13 days between the learning and the testing of a series two more rounds of similar series were learned. When the particular test is not mentioned it is always the *final* one that is meant. By 'wing' is meant the three terms on either side of the middle term.[1]

Subject R.

Col. Sizes I and II, and Cols. A. In learning Col. Sizes I the only error was an exchange of 3 yellow orange and 4 blue green belonging in 2d and 6th places respectively. The error was probably due to their similarity in size. It occurred three times on successive days. When the next week Col. Sizes II was learned the influence of I was shown in erroneously moving green *yellow* from 5th to 1st place where a yellow *green* had stood the previous week. The error occurred twice, with no others. When in the third week Col. Sizes I received its final test, aside from an exchange of two small adjacents, 3 yellow orange and 1 red, the only error was a removal of yellow *green* to 5th place. Here the corrections which the subject got in II worked to the undoing of I. When the following week II is tested the only error is moving green yellow to the left end, this time to second place instead of to first. The original error has recurred. Cols. A, which was learned with Col. Sizes I, shows the influence of this struggle. Its yellow orange is moved from 2d to 7th place, its green from 5th to 3d place. This is very much like the first-mentioned error in Col. Sizes I. The only other errors were an exchange of adjacents, violet blue and red.

C. F. d. S. III. Exchange of adjacent terms in final test, one pair only.

Forms I. In the final test aside from one exchange of adjacents, the errors are caused by moving Fig. 7 to 3d place. No explanation ascertainable.

Sizes B and C. The kind of schemes or systems most frequently made use of by all the subjects when the exposure was simultaneous is well illustrated by the one used by R in Sizes B. The correct order was 3416275, 1 representing the smallest, 2 the next smallest term, etc. Her system according to her own testimony was an ascending 'sky-line' from 1st to 6th places, 3467, the smallest and next smallest forming a second ascending series interpolated in the first at the 3d and 5th positions. The last term stood apart. In the final test the general nature of the scheme remains, but the details have become

[1] To understand these analyses of errors the Description of Series on pp. 74–80 doubtless will have to be frequently consulted. The prefixed figures 2, 3, etc., mean the second size, third size, etc, counting from the smallest.

confused, as shown by her arrangement 3451726. The next week, when Sizes C came up for final test the system which the subject had employed in learning B was introduced into C with entire correctness. The subject is of course unaware that it had belonged to another series. This is only one of the many striking illustrations in our experiment of the law discovered by Müller and Pilzecker, that of two similar and mutually interfering associations the earlier formed one becomes relatively stronger, the greater the lapse of time since the later one was learned.[1] In our own illustration the system used in B was imperfectly remembered when still in the shadow of learning C, but after the effects of learning C had had a week to die down, the B system recovered, unfortunately for the subject, in the wrong series.

Forms II. This series has three tall figures, distributed near the middle and on or near the ends. In learning, the series was balanced about them and on one occasion Fig. 5 was put in the middle place. After two weeks the subject has forgotten the exceptions to the balanced scheme, as shown by her arrangement, in which the three tall figures of the series are placed at the ends and in the middle. Fig. 2 is on the left, 5 in the middle and 7 on the right end. The low intermediate figures are not well remembered.

C. F. d. S. IV. Figs. 5 and 6 are exchanged. Possibly their similarity in size was a partial cause. The other error was moving Fig. 1 to the right of Fig. 7, of which no explanation other than simply memory-fading is offered. Both errors in the final test only

Cols. II. Many errors in final test. No explanation.

Cols. I. Final test. Again the arrangement is chaotic. Bright colors (red and green) are erroneously put in the middle where they were in the three other color series previously learned.

Col. Sizes A. The final test is badly mixed. The subject places only one term correctly,—2 red orange. 4 blue green and 3 blue are exchanged. They are next to each other in size and similar in color.

C. F. d. S. I. A single exchange of adjacents, Figs. 2 and 3.

C. F. d. S. II. Two exchanges of adjacents, Figs. 2 and 3, and 4 and 5. Shows interference of other series: Fig 6 (window)[2] is put in 1st place, occupied in C. F. d. S. III (which preceded the present series with this subject) by a figure of the same shape, but different color and size. Fig. 1 (slender vase) is put in 6th place as in Forms B, seen 1 day before.

Col. Sizes B. Three errors. Ends, blue and orange red, are exchanged, due, the subject says, to Cols. A, where a similar blue and red were on the ends. Latter series not seen for 30 days. Orange yellow moved to the right of the term belonging in 6th place. Reason not known.

[1] Müller and Pilzecker.: Ztsch. f. Psych., Ergänzungsbd. 1, pp. 124 and 138.
[2] These names are inventions of the operator.

Cols. B. Exchange of the two terms considered colorless or 'dead' by the subject, A-yellow light and warm gray no. 2.

Col. Forms I. All correct.

Forms B. An exchange of two figures adjacent and relatively very similar in shape, Figs. 4 and 5 (irregular octagon and double crescent).

Sizes A. Another typical illustration of the schemes used by all the subjects in the sizes of the simultaneous set. The correct order was 5416372. Her system consisted, she says, of three 'sky-lines:' the first a descending one formed by the terms 541, the second an ascending one formed by the terms 167, the third an ascending and descending one formed by the three smallest terms. Despite the small total area of the series and consequently greater difficulty in discriminating the terms the system served its purpose pretty well. After 13 days and many series learned in the interval the subject got the whole series correct except a single exchange, the smallest and third smallest. She remembered and used the system in reconstruction, but forgot the third 'sky-line.'

Col. Forms III. Influence of an introspection series given two and one-half months before causes the subject to put Fig. 5 (inverted hat) in 1st place, where a figure of the same shape and size, but red instead of yellow had stood. The other errors are displacements caused by this change.

Col. Forms. IV. All correct.

Col. Forms II. Poorly recalled and no special reason evident.

Sizes I. Same result as in Col. Forms II.

Forms A. Its mediocre retention is explicable on the basis of its extremely short learning time, 10 secs. The equal-armed cross, Fig. 3, is put in 5th place, where the larger long blue cross was in C. F. d. S. II, 20 days before. The other errors are exchanges of adjacents.

Forms III. In learning, a similarity between Figs. 6 and 7 and the number 10 was noticed. In final test Fig. 4 took the place of Fig. 6 in this idea. This brought Figs. 3 and 5 together forming an unnatural looking low 'sky-line' at this point, which R broke by putting Fig. 2 between Figs. 3 and 5. The two latter were also transposed. Note their similarity.

Col. Sizes III. In learning, the only error was an exchange of 6 and 7, which are not only similar to each other in size (and in color to this subject), but are also similar to the two largest areas of Sizes II (learned at the same time) in respect to the positions occupied. The exchange was a copy of the positions of 6 and 7 in the other series. Same error repeated in the final test, and also made by the subject next to be discussed.

Sizes II. Confused with the series just mentioned. In final test 6 and 7 were placed as they should have been in that series. Further errors in this series were moving 4 to left end and 1 to a place in the middle, both in imitation of Col. Sizes III. The remaining errors cannot be traced.

Cols. III. Her learning scheme was: 'group of the left three were pronounced colors, yellow first, purple and red next, the last two a displeasing combination. Group of the right three consists of a pale one (green tint) followed by two neutral colors. Blue associated with middle, a conspicuous position.' In final test the left three were correctly recalled, but green gray was put in the middle, with which place a gray had been connected in the week intervening between the learning and final test of this series (viz: in Cols. IV). The cue for the right three was forgotten.

Sizes III. Too poorly recalled to analyze. The left three have the regularly increasing size arrangement of the original, but do not begin with the exactly correct size.

Col. Sizes IV. An almost complete copy of her last week's arrangement of Col. Sizes III, which she had recalled uncommonly well. The order there was 3465172 instead of 3475162. The order here was 3465271. The only difference is an exchange of the two smallest. This is very different from what the series should be, viz: 3162547.

Sizes IV. Too poorly recalled to analyze. Her arrangement is similar in a general way to the original in the fact that each wing consists of a large one flanked by smaller ones, but the wings are exchanged.

Forms IV. In final test exchange of Figs. 5 and 6, due to the identity of Fig. 7 with a part of Fig. 5. The confusion of similars most frequently shows itself by an exchange, partial or complete, but it seems not unlikely that at other times it results in bringing together the terms confused. This is very plainly the case here and in Cols. IV with the next subject, N. The remaining error in Forms IV was an exchange of Figs. 1 and 3.

Cols. IV. In learning, red and green in 3d and 5th places, with gray between them, formed a group. The complementary character of red and green, noted by the subject, is both a help and a risk. They were exchanged once in learning, and in final test green is again put in place of red, the latter being displaced to 2d place. The other error consists in putting blue tint in 6th place, where R had wrongly put a similar color last week. (Green blue in Cols. III.)

Subject N.

Cols. A. Influenced by Cols. II learned the week before, three colors being placed as were similar colors in that series. Blue is moved from 1st to 3d place, red from 7th to 5th and green from 5th to 6th. The other errors result from these displacements.

Forms I. Exchange of adjacents, Figs. 4 and 5.

In discussing four of the series immediately following this chronological table will be of service.

7th week. Learned Sizes B and Col. Sizes I.
8th week. Learned Sizes C and Col. Sizes II.
9th week. Final test of Sizes B and Col. Sizes I.
10th week. Final test of Sizes C and Col. Sizes II.

Sizes B. The correct order is 3416275. In final test the subject gave 3451726,—an exchange of sizes 6 and 7, and a removal of 5 to 3d place. The latter error gives a longer 'sky-line' in the first three terms, a peculiarity which may have been due to Sizes C learned the preceding week. Both the peculiar shape of the terms in this latter series and their order (26, 457, 13) emphasized lines ascending to the right. All of the subjects spoke of this and considered it rendered the series easier.

Col. Sizes I. Same erroneous idea of pronounced upward slope in the final test of this series. Instead of the correct order, 2317645, 3457126 is given. From the point of view of size this cannot be anything else than two upward slopes.

C. F. d. S. III. Exchange of Figs. 5 and 7. No similarity.

Forms II. Two exchanges of similar forms, Figs. 2 and 5, and 3 and 6.

C. F. d. S. IV. Fig. 8, a small inverted hat, moved to the left of Figs. 4 and 5. No reason apparent.

Col. Sizes II. Final test was the same as in Sizes B, with a slight change. Here it is 2351746. There it was 3451726.

Sizes C. In the final test the subject's arrangement was 3451726, the correct order being 2645713. This is exactly the same mixture of B and C which the subject employed in the final test of B, a week before.

Col. Forms IV. One displacement, Fig. 6 moved to the left of Fig. 4.

Cols. II. All correct,—very unusual. His scheme was: 'The heaviest (red) with the two lightest (yellow and green tint 1) on either side, were next to the right end (4th to 6th places). Of the remainder a light one (orange red tint 2) was on the left end followed by two heavy ones. The one in 7th place was correctly placed by being left over after the others had been arranged.'

Cols. I and B. I preceded B a week in learning. In final test I shows plainly the influence of subsequently learning B. The only error is a removal of green yellow and red orange shade from 6th and 7th places to 2d and 3d, and a consequent rightward displacement of 2–5. This is approximately the position of a bright red and yellow in B, namely, 3d and 4th positions. B, however, is also affected in its final test the next week. The interference is mutual. Aside from an exchange of adjacents (5th and 6th) the only error is a removal of green from 7th to 2d place where a bright green stood in I.

Col. Sizes A. The errors are due to a confusion of terms within the series, similar to each other in size and color. All of the subjects experienced this difficulty. The similarities in color constituted a defect in the series, and

were one of the reasons why it was rejected from the regular series. In the case of this subject the errors were an exchange of 3 blue and 4 blue green, and of 5 green tint and 6 A-green yellow.

C. F. d. S. I. Two exchanges of adjacents.

C. F. d. S. II. This series shows interference of other series. Only the 1st and 4th are correctly placed. Fig. 7 (spire) is moved to second place occupied by a figure of the same shape but different color and larger in Col. Forms II seen 5 days before . Fig. 5 (tall cross) is put in 3d place occupied by a maltese cross of a very different color and size in C. F. d. S. IV. Fig. 2 (trademark) is put in 6th place. The same figure but very much larger and of slightly different color had been in 7th place in C. F. d. S. IV. Fig. 3 (pin-wheel) is put in 7th place where a figure of the same shape but different color and size had been in Forms II. C. F. d. S. IV. and Forms II. were last seen 31 days before.

Col. Sizes B. Recall too poor to analyze.

Forms B. Fig. 4 moved to 1st and Fig. 7 to 4th place. No explanation.

Sizes A. Exchange of sizes 2 and 3, and 4 and 5.

Col. Forms I. Exchange of adjacent Figs. 4 and 5.

Col. Forms II. All correct. The subject said: "Figs. 3, 4, and 5 were recalled by the appearance of the three as a group. Figs. 1 and 7 were associated with their positions, and Figs. 2 and 6 were contrasted with each other and associated with their positions.

Forms A. Interference of other series. Fig. 7 (wide vase) put in first place where a slender vase of different color had been in C. F. d. S. II 12 days before. Exchange of Figs. 5 and 6. Fig. 3 (equal-armed cross) put in 7th place for no apparent reason.

Sizes I. Exactly the same arrangement as was given for Sizes C 43 days before!

Sizes II. In learning the only error was arranging the series once in the exact arrangement of Col. Sizes III. Despite the correction which it had received, the same mistake was made in final test, the only alteration being an inversion of the last two terms.

Col. Sizes III. An illustration of the fact that the interference is always mutual. This series and Sizes II, learned at the same time, were confused with each other. The other series fared the worst, but in the final test of this series, 6 and 7 were arranged as they were in that series. There was also an inversion of the last two terms, as in Sizes II.

Col. Forms III. Fig. 5 (inverted hat) put in 1st place, occupied by a figure of the same shape and size, but different color, three months before in an introspection series. The only other error, aside from the rightward displacement of Figs. 1, 2 and 3, was an exchange of the similar figures, 4 and 6 (tombstone and knobbed oblong).

Forms III. One error in final test, an exchange of the obviously similar figures, 3 and 5 (pentagon and pentagon with curved upper sides).

Colors III. The errors were two exchanges: one of green yellow and orange yellow, similar colors, the other of colors not similar. The association of a smaller figure of the same color as one of them with the place where one of these two is put, may have been the cause. The interval was a week.

Sizes III. In final test the arrangement is quite similar to the correct order in a general way, but not in detail. Instead of 2451376 is given 3561274. This series and the next two are good illustrations of interference within a series due to poor perceptual discrimination, the kind which Ranschburg found in his six-place numbers. The very fact that the arrangement is similar only in its general contour as a whole shows incomplete perceptual discrimination of similar things, of the kind that he found.

Sizes IV. Confused with Sizes III, learned at the same time. Once in learning it was given as 3461275, the correct order of Sizes III being 2451376. The only other error made in learning was a removal of 3 from one end to the other. In the final test there was a general resemblance to the correct order. 3741265 is given in place of 4761253. It is true that the correct orders of III and IV somewhat resemble each other, but in the former the two largest are on the right, while in the latter they are on the left end. In the final arrangement of IV, the largest is back in place.

Col. Sizes IV. 1 and 4 exchanged in final test, due to an exchange of 3 and 4 in learning. Cf. their positions in the correct order, 3162547.

Forms IV. Adjacent Figs. 2 and 3 exchanged in final test.

Col. Forms IV. Figs. 5 and 7 exchanged. No similarity.

Cols. IV. Too poorly recalled to analyze. Black, 1st place, and gray, 4th place, moved to 3d and 2d places respectively,—an instance of similars brought together.

There were also 6 exchanges of numbers belonging to sizes nearest each other in area, which occurred during the learning of some of the above series, and which have not been heretofore mentioned.